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Morphological and Mechanical Property Analysis of Rice Husk Reinforced Polypropylene Composite

by

Nayan Rimal

A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Morphological and Mechanical Property Analysis of Rice Husk Reinforced Polypropylene Composite" submitted by Nayan Rimal in partial fulfillment of the requirements for the Degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

A polymer is a large molecule made up of many subunits. In general, pure polymer is rarely used due to the fact that the most of the physical properties gets enhanced if used in combined form, called composite. Polymer composite refers to the material, that consists of polymer as a matrix or resin and natural fiber reinforcing as a filler, that can improve mechanical properties when compared with pure polymeric materials. The inherent properties of rice husk, such as its abundance, low density, and biodegradability, make it an attractive candidate for enhancing the tensile, flexural, and impact strength of resultant composite material. Previous research provides information regarding polypropylene, Rice Husk and the property of their composite. This study deeply explores the usage of rice husk as a renewable, sustainable and cost-effective filler by varying proportion (10, 20, 30 and 40%) and size (below 212, 212 to 425 and 425 to 1000 microns) to improve the mechanical performance of Polypropylene-based composite, demonstrating the relation between variation of temperature, filler size, filler proportion with the property and structural integrity of composite. First, the samples of polypropylene and rice husk in size and proportion variation were made. The grain structures were observed with the help of stereo-microscope up to 100 times optical magnification and digitally further 10 times. The samples of composite as well as pure polypropylene were tested to determine mechanical property that includes tensile and impact test. The data from individual test sample were compared and there was substantial improvement in mechanical property on some cases. The sample with rice husk particle size of 212 to 425 microns with 20% filler proportion at 220ºC was found to be the best sample regarding tensile property. However, elongation was found to be decreased on every composite when compared with pure polymer.

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LIST OF ABBREVIATIONS

PP	Polypropylene
RH	Rice Husk
LDPE	Low Density Polyethylene
HDPE	High Density Polyethylene
MPa	Mega Pascal
UTM	Universal Testing Machine

CHAPTER ONE: INTRODUCTION

1.1 Background

As the demand for environmentally friendly materials rises, along with soaring costs of petroleum-based plastics and stringent environmental regulations, there is a growing interest in the field of composites. When two or more materials are combined together in order to improve their properties, the resulting material is called Blends or Composites. Blends composed of variety of similar-nature material. For example, blend of polymers. Composite consists of different-nature materials, like polymer and non-polymer, normally two types: one act as a housing, to provide other material to integrate, also called matrix whereas other acts as a reinforcing component, called filler. When at least one material has biological origin, the composite is referred as bio-composite (Premalal et al., 2002).

Generally, polymer composites are composed of a polymer matrix as the main material and can include one or some filler material to meet some criteria. For instance, aerospace and sports applications demand composites with high mechanical and thermal properties (Arjmandi et al., 2015). Traditionally, synthetic fibers like carbon or glass fibers have been employed to strengthen these composites, enabling them to possess such properties. Nevertheless, the slow biodegradability of these synthetic fibers has become a drawback, particularly due to increasing global environmental concerns. As a result, researchers are exploring alternative approaches to enhance or expedite the biodegradability of polymeric composites. Consequently, natural fibers are showing great promise as reinforcement fillers in thermosets, thermoplastics, and elastomers. Utilizing natural fibers in composites offers several advantages, including lower cost, sustainability, lightweight characteristics, and non-abrasive, non-hazardous properties. Most importantly, they contribute to accelerating the biodegradation of polymeric composites (*With Increasing Numbers of Applications and Mass Volume Uses, in Particular, Recording Double-Digit*, 2003).

Rice husk is a byproduct of rice processing, which is quite cheaper, and is segregated during the process of rice milling. Rice is one of the most popular crop in countries such as India, Nepal, Indonesia, Bangladesh, China and Malaysia (Bishwajit et al., 2013).

Burning rice husk is discouraged due to the potential emission of noxious fumes and harmful gases, which contribute to environmental deterioration. When producing composite materials using rice husk, there is a suboptimal interaction between the rice husk and the matrix materials, leading to a weak bond between particles and the matrix (Wei et al., 2013). While earlier research suggested that rice husk particleboard could be utilized in furniture and similar structures, it exhibited inferior physical and mechanical characteristics compared to particleboards made from wood particles (Awang & Wan Mohd, 2018). When RH is incorporated into polymer matrices, it imparts several advantageous qualities, including biodegradability, lighter in weight, durability, and resistance to weathering. Additionally, this incorporation enhances the economic competitiveness of the final products. In comparison to wood composites, Rice husk filled polymer composites exhibit better resistance to biological damage, as well as improved dimensional stability when exposed to moisture. As a result, these composites are increasingly finding applications in construction areas, such as window and door frames, sliding materials, decks, interior panels, etc. They are also gaining popularity in the automobile sector for interior components like door panels (Santiagoo et al., 2011).

1.2 Problem Statement

The use of PP solely, without any reinforcement, has considerably lower mechanical strength, tendency to cracking and shrinkage. The introduction of filler material in the polymer matrix helps to overcome such problem. Rice husk, being one of the cheaper and easily available natural resource, can become a suitable filler material for the PP.

1.3 Objective of Study

1.3.1 Main Objective

The main objective of the study is to perform morphological and mechanical property analysis of rice husk reinforced polypropylene composite.

1.3.2 Specific Objectives

The specific objectives of the study are:

i. To build composite samples with varying: RH proportion, RH particle size and molding temperature

ii. To perform mechanical testing on the composite

iii. To perform morphological analysis on the composite sample

iv. To perform water absorption test

v. To obtain optimal sample among various parameters

1.4 Assumptions and Limitations

The assumption made during the course of study are:

i. Absence of foreign material affecting the structural integrity of matrix and filler material.

ii. The particle size of RH was considered uniform in each sample.

CHAPTER TWO: LITERATURE REVIEW

2.1 Polypropylene

Polypropylene is a highly versatile thermoplastic polymer known for its favorable physical characteristics. It possesses a density that ranges from 0.895 to 0.92 g/cm³, which gives it a relatively low mass, while still maintaining impressive tensile strength, typically falling within the range of 25 to 45 MPa. Additionally, it has a moderate Young's modulus of approximately 1,400 MPa. Its melting point, a crucial factor in the manufacturing process, falls within the range of 130 to 171°C, making it easily moldable and shapeable. It has a coefficient of thermal expansion of approximately 80-110 x 10^{-6} /°C, indicating that it maintains relatively stable dimensions when exposed to varying temperatures. This material also possesses good resistance to chemicals and exhibits low water absorption, with a rate of less than 0.1% (Ahmad FuAo et al., 1995).

Being a thermoplastic polymer, polypropylene (PP) presents numerous benefits that render it the preferred option for composite applications. Its low density leads to the creation of lightweight composites, which proves exceptionally advantageous in industries where minimizing weight is crucial, such as the automotive and aerospace sectors (Razavi-Nouri et al., 2006). The outstanding chemical resistance of polypropylene (PP) guarantees durability and protection against a broad spectrum of chemicals. This attribute extends the lifespan of composite structures in harsh environments. PP's ease of processing and compatibility with diverse reinforcement materials like glass fibers, carbon fibers, and natural fibers allow for the customization of composite properties to meet precise performance criteria. Its relatively low processing temperatures and high melt flow characteristics also simplify cost-effective and efficient manufacturing techniques such as injection molding, extrusion, and compression molding. This accessibility enables large-scale production of PP-based composites, ultimately reducing overall production expenses. (Ahmad FuAo et al., 1995b).

Polypropylene also demonstrates favorable mechanical properties, which encompass a well-balanced combination of strength, stiffness, and resistance to impact. When integrated into a composite, PP can enhance these characteristics, making it well-suited for structural applications that require robust mechanical performance. This versatility has led to a wide array of applications for PP. In the automotive sector, PP composites find use in interior components like door panels, dashboard trims, and seat structures, taking advantage of their lightweight nature, impact resistance, and cost-effectiveness. In construction, PP composites are employed for exterior cladding, roofing materials, and piping systems due to their durability and resistance to environmental factors, as well as their ease of installation. Furthermore, PP composites are applicable in various other areas, including industrial appliances, medical devices, and home furnishings, among others. (Grozdanov et al., 2006).

2.2 Rice Husk

Rice husk, which forms the outer protective layer of rice grains, possesses several noteworthy physical characteristics. It is generally lightweight, with a density typically falling within the range of 130 to 160 kg/m^3. The moisture content of rice husk varies between 10% and 15%, which affects its flammability and how well it can be stored. Additionally, its bulk density is approximately 75-80 kg/m^3, which has implications for how it can be handled and transported. (Rabbani et al., 2022). RH is a fibrous material primarily composed of cellulose, known for its abundant supply, remarkable toughness, natural abrasiveness, and distinctive composition, resulting in a wide range of aspect ratio (Luna et al., 2015).

From a functional perspective, rice husk offers remarkable advantages when incorporated into composite materials, providing reinforcing and enhancing effects. It contains a substantial amount of amorphous silica, which, when properly integrated into the composite matrix, can improve mechanical properties like stiffness, strength, and abrasion resistance. Furthermore, the unique microstructure of rice husk particles promotes enhanced bonding between the filler and the polymer matrix, resulting in improved overall mechanical performance of the composite. Rice husk's relatively low density also contributes to the development of lightweight composites, a valuable feature in industries where reducing weight is a priority, such as the automotive and aerospace sectors. Additionally, its thermal insulating properties can be advantageous in applications that require precise temperature control. The natural abundance and cost-effectiveness of rice husk as a filler material make it an economically attractive choice, reducing production costs while either maintaining or even enhancing the performance of the composite. (Ishak et al., n.d.).

The cost-effectiveness and abundant availability of rice husk render it an appealing filler option, with the potential to lower the production expenses of PP composites while either preserving or enhancing their performance attributes. Incorporating rice husk as a filler material into PP composites represents a sustainable strategy that combines environmental friendliness, enhanced mechanical properties, thermal insulation, and cost-efficiency (Martí-Ferrer et al., 2006).

2.3 Injection molding

It is a process in which a polymer is heated to a molten plastic state and constantly pressurized it to flow using a carrier into a mold cavity, where it solidifies. The first step is to feed polymer pellets and filler particles into the hopper, which then feeds into the barrel (Ashori & Nourbakhsh, 2009).

2.3.1 Screw Extruder

In the screw extruder of plastic molding process, a heated barrel contains a rotating screw that crushes plastic pellets, facilitating their liquefaction. Towards the front of the barrel, the rotating screw propels the molten plastic forward, directing it through a nozzle and into an empty mold. Unlike the barrel, the mold is maintained at a cool temperature to solidify the plastic into the desired shape. The mold plates are held securely closed by a sizable plate, known as a movable platen, which is connected to a hydraulic piston applying pressure to the mold. This clamping action prevents any plastic leakage, ensuring the final pieces are free from defects. This process yields discrete components that are typically very close to their final shape, and the production cycle generally spans 10 to 30 seconds, although longer cycles of a minute or more are not uncommon for molding certain parts (Yiga et al., 2020).

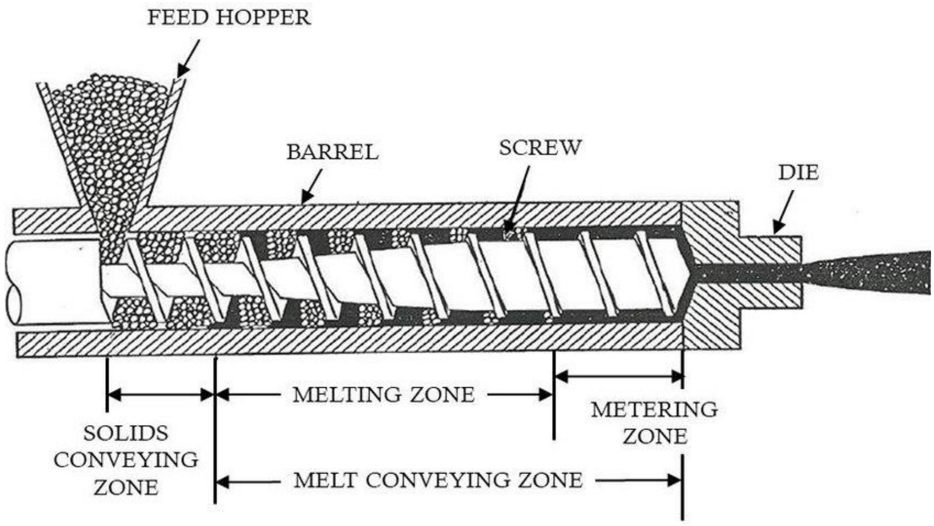

Figure 1: Screw Extruder (source: Shrivastava, 2008)

2.4 Morphological analysis

2.4.1 Stereo microscope

A stereo microscope, also known as a dissecting microscope, is a specialized optical instrument that provides three-dimensional, magnified views of objects with exceptional clarity and depth perception. Unlike compound microscopes that utilize transmitted light and high magnification for viewing transparent specimens, a stereo microscope employs a binocular setup to observe larger, opaque objects. It features two eyepieces that offer a magnified, stereoscopic view of the specimen, allowing for detailed examination of its surface characteristics, texture, and intricate structures (*Stereo Microscopy — Metallurgical Engineering Services*, n.d.).

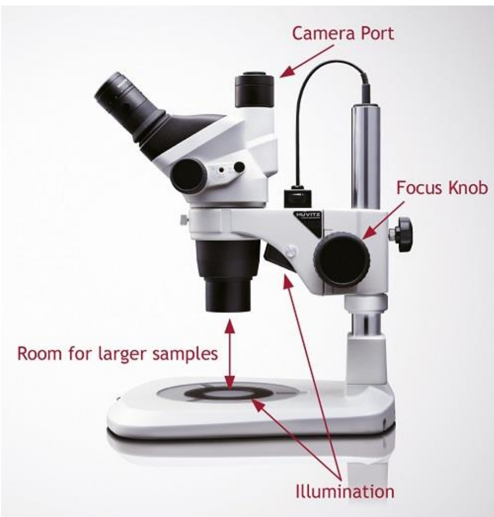

Figure 2: Stereo microscope (source: www.microscopeworld.com)

By utilizing the stereo microscope's binocular vision and three-dimensional imaging capabilities, the arrangement, distribution, and interactions of different components within the composite matrix can easily be observed. This includes analyzing the dispersion of reinforcing fibers, fillers, and additives, as well as assessing the quality of bonding between different phases. The stereo microscope enables precise observation of composite surfaces, identifying defects, voids, or irregularities that could impact the material's performance. Additionally, the microscope aids in characterizing the texture, morphology, and microstructure of composite samples, contributing to a comprehensive understanding of how these materials behave under various conditions. This information is invaluable for optimizing composite formulations, enhancing mechanical properties, and ensuring the quality and reliability of composite materials in diverse applications (Kenes et al., n.d.).

2.5 Mechanical testing

To enhance the mechanical characteristics of the composite, research has explored the impact of different factors, including filler concentration, particle size, and processing variables. Increasing rice husk content in composite formulations often results in heightened stiffness and strength, though a careful equilibrium must be maintained to prevent adverse impacts on other properties. Furthermore, the particle size of rice husk has been observed to affect mechanical performance, with finer particles typically facilitating improved dispersion and interfacial adhesion (Toro et al., n.d.).

2.5.1 Universal Testing Machine

It serves as a versatile mechanical testing device used to assess the mechanical properties of various materials. It consists of a load frame with grips or fixtures for securing specimens, a load cell for measuring force, and an actuator for applying controlled loads. A control system oversees testing parameters, while a data acquisition system records load and displacement data.

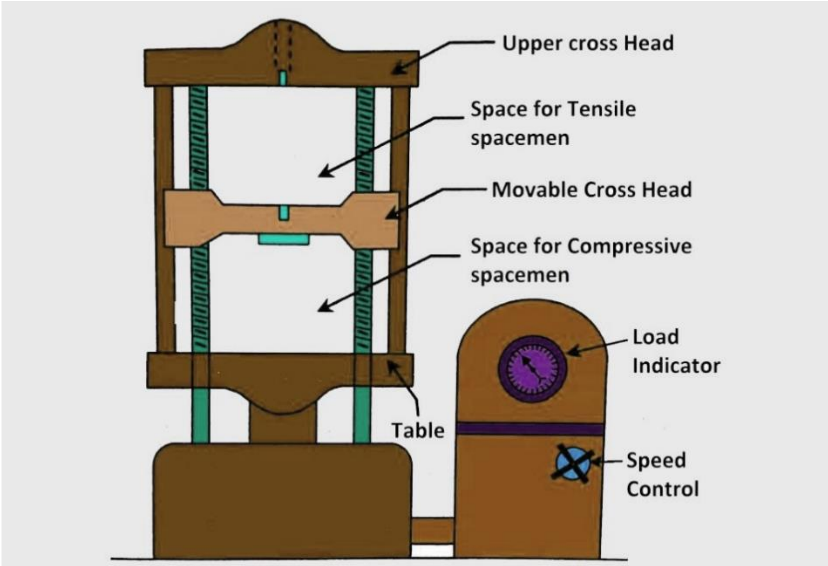

Figure 3: Universal Testing Machine (source: Singh, 2013)

A comprehensive suite of tests, including tension, compression, bending, shear, and torsion, is conducted to gain crucial insights into material performance, supporting a wide range of industrial activities such as material selection, research, quality assurance, and product safety. The essential components of this testing system consist of a load frame, which functions as the structural support for the specimen, grips or fixtures designed to securely secure the specimen, a load cell for measuring applied force, and an actuator responsible for applying controlled loads to the specimen. Furthermore, a control system regulates test parameters like load rate and displacement, while a data acquisition system captures and records data such as load and displacement during testing. These integral elements collaborate to facilitate various mechanical tests, encompassing tension, compression, bending, shear, and torsion, providing invaluable insights into the mechanical characteristics and behavior of diverse materials for applications across materials science, engineering, manufacturing, and quality control. (Saritha et al., 2023).

2.5.2 Impact Test

An impact test is a dynamic examination involving a typically notched specimen, struck and fractured by a single blow within a specially devised apparatus. This process measures the energy absorbed during specimen breakage. The test's objective is to gauge material toughness and its capacity for energy absorption. The energy values obtained are qualitative assessments specific to the chosen specimen and cannot be directly converted into energy data applicable for engineering design calculations (Adams & Adams, 1989).

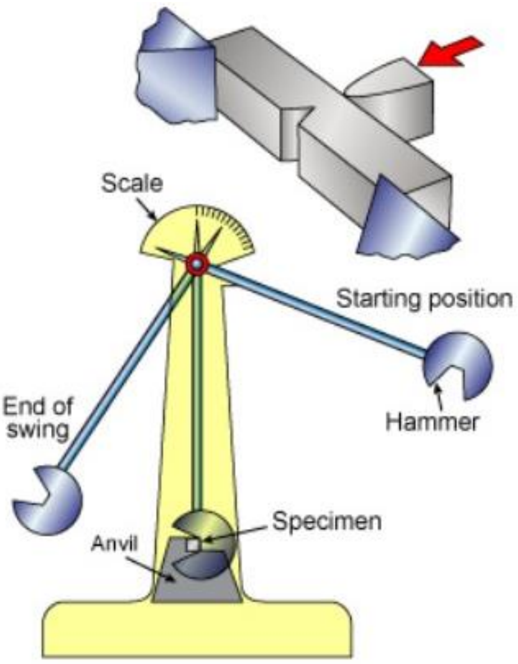

Figure 4: Impact test (Source: impactmateria.com)

Impact testing is done by adopting among two tests:

a) Charpy Test

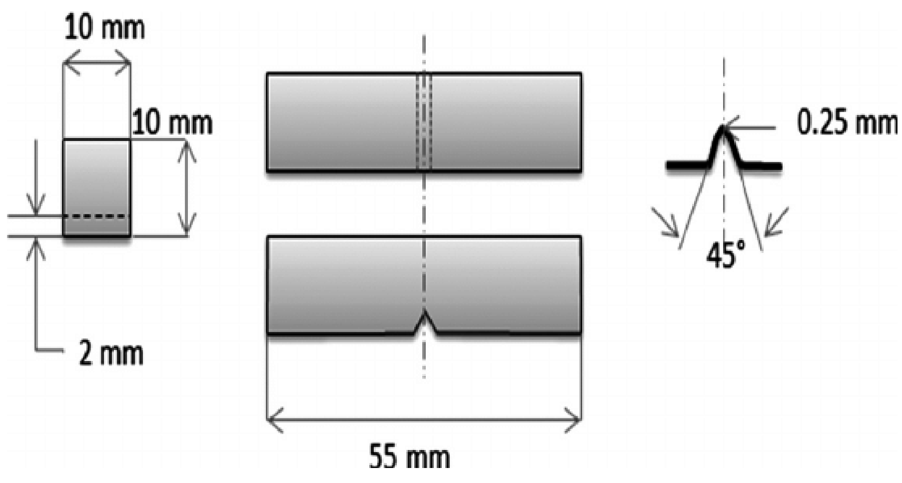

Figure 5: Charpy test specimen (source: Barbosa et al., 2012)

b) Izod Test

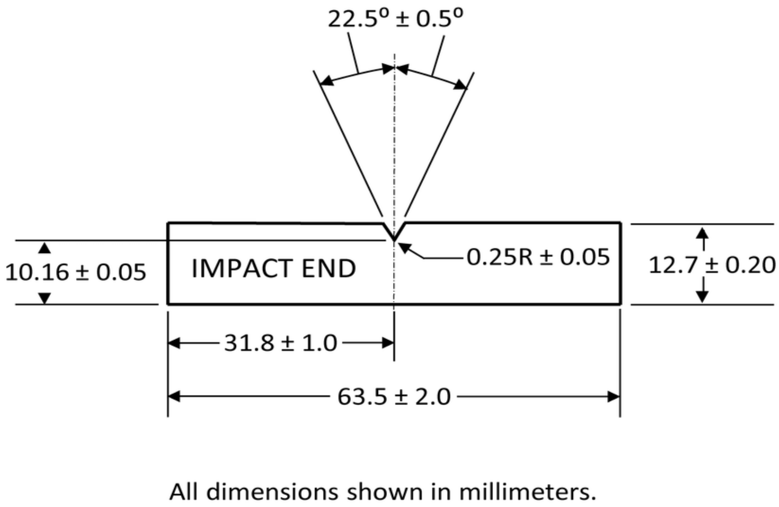

Figure 6: Izod test specimen (source: Patterson et al., 2020)

The principal difference between two tests is the size of specimen. In the Charpy test the specimen is supported as a simple beam with a notch in the center. The specimen is supported so that the notch is on the vertical face away from the point of impact (Nascimento et al., 2018).

2.6 Related works

In a notable work by Ismail et al., (2003), 40% weight of RH with rest PP was taken optimum tensile strength was found. With 25% of weight of filler-loading: optimal regarding Young's modulus, flexural strength, flexural modulus, and impact strength were observed. Likewise, during SEM analysis: as filler loading increased, more voids and fiber pullout occurred.

Morphological studies have also played a main role in demonstrating the internal structure. Toro et al., (2005) utilized scanning electron microscopy (SEM) to analyze the dispersion of rice husk particles within the polypropylene matrix. Their work highlighted the importance of proper processing techniques to achieve uniform dispersion and mitigate particle agglomeration. In a different approach, Aridi et al., (2016) used X-ray diffraction (XRD) to study the internal structure of the composite, that revealed the changes in polymer crystallinity with varying rice husk content.

Razavi-Nouri et al., (2006) observed that the tensile and flexural modulus of the composites containing 40% of RH increased approximately by 33% and 100%, respectively. Likewise, by increasing RH%, flexural strength was moderately improved elongation-at-break and energy-at-break decreased dramatically.

Furthermore, the work of Ashori & Nourbakhsh, (2009) investigated the impact of composite morphology on dynamic mechanical properties. Their research employed the analysis to investigate the storage modulus and damping behavior of the PP-RH composite. The results indicated a shift in glass transition temperature and altered viscoelastic behavior due to the incorporation of rice husk, offering insights into potential applications in vibration damping materials.

Afridi et al. (2016) performed study by varying rice husk proportion from 20% to 40% and found that the optimum tensile strength was shown by the 40% filler-loaded sample and at 25%, the Young's modulus, flexural strength and impact strength were found to be improved. From SEM analysis, as filler loading increased, more voids and fiber pullout were observed.

Likewise, Miguel Angel (2019) carried out test on 10, 20 and 30% rice husk proportion samples. The tensile and flexural modulus increased up to 63 and 75% respectively as compared with pure polypropylene. Also, the elongation at break was decreased with increasing filler loading.

Some studies have also explored the influence of processing techniques on composite performance. (Yang et al., n.d.) investigated the effect of compounding methods, comparing melt mixing and extrusion techniques. Their findings indicated that the extrusion process led to better dispersion and improved mechanical properties compared to melt mixing.

All of the previous research provides information regarding PP, RH and the property of their composite. However, the relation between variation of temperature, filler size, filler proportion with the property and structural integrity of composite, has not been analyzed deeply. Additionally, the effect of cooling rate on the die, right after injection molding, has not been studied well.

Addressing these research gaps identified in prior studies, it is essential for advancing understanding and knowledge on those particular aspects. The present study aims to bridge these gaps by delving into aforementioned areas that have received limited attention.

CHAPTER THREE: METHODOLOGY

The methodology followed during the thesis is as in the figure 7.

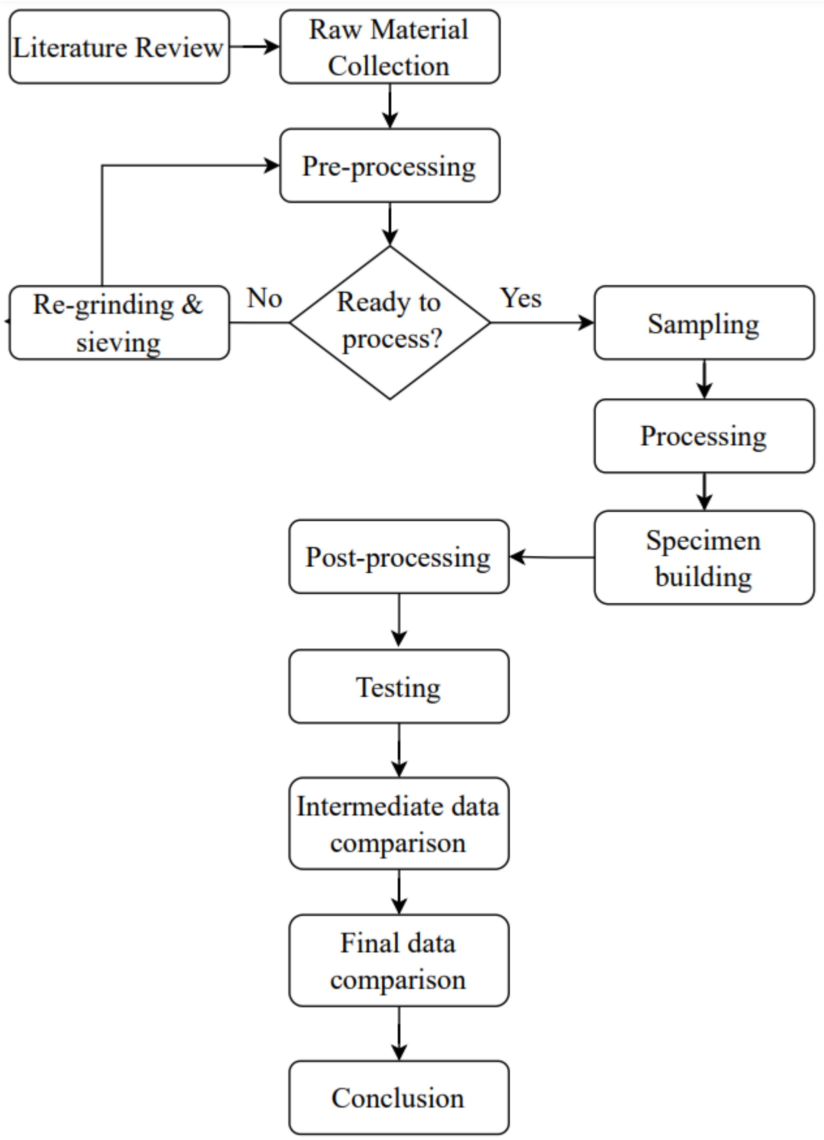

Figure 7: Methodology of the research

3.1 Literature review

A considerable portion of the research has been covered by the literature review. Books, journals, papers and articles have been thoroughly studied, reviewed and continued till the end of the research. The literature mainly focusing on the properties of PP and RH, crushing and segregation process, sampling of different proportions was thoroughly studied to obtain the required background for the research.

3.2 Raw material collection

The composite includes Polypropylene as polymer and Rice husk as filler material. 10 Kg of PP and 5 Kg of RH was collected.

Figure 8: Rice Husk

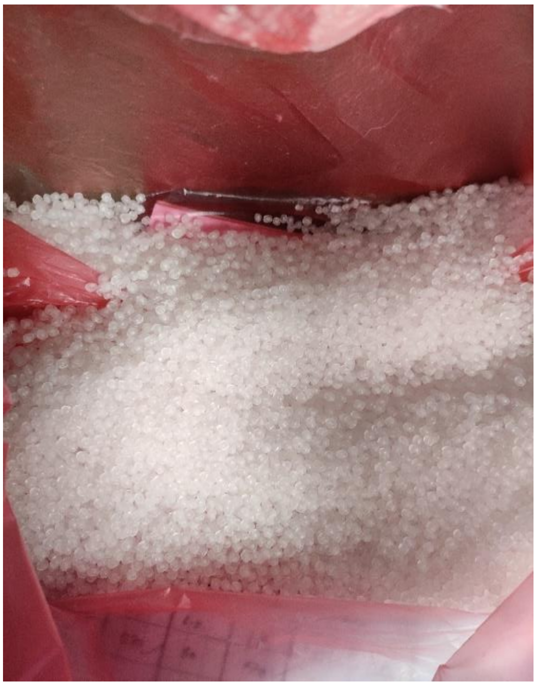

Figure 9: Polypropylene

3.3 Pre-processing

3.3.1 Grinding

It consists of grinding and separating various size RH particles (212 microns, 425 micron and 1000 micron) in order to mix with PP during processing. Rice husk was ground with 550 watt grinding mixer that is commonly used in household application as shown in figure 10.

Figure 10: Grinder for making finer RH particles

3.3.2 Screening

After grinding, the ground products were placed on top of sieve. Three layers of sieves, overlying on top of each as shown in the figure 11, screens the product with respect to their mesh size: 1000 microns, 425 microns and 212 microns, from top in decreasing size order.

Figure 11: Set of three sieves

The residues left were re-ground and sieved repeatedly until required amount of the product are obtained.

3.3.3 Drying

Any humidity present in the RH particles after screening were removed by heating and drying inside the Incubator, which acts as an Air-drier, as shown in figure 12 and 13.

Figure 12: Air-Direr

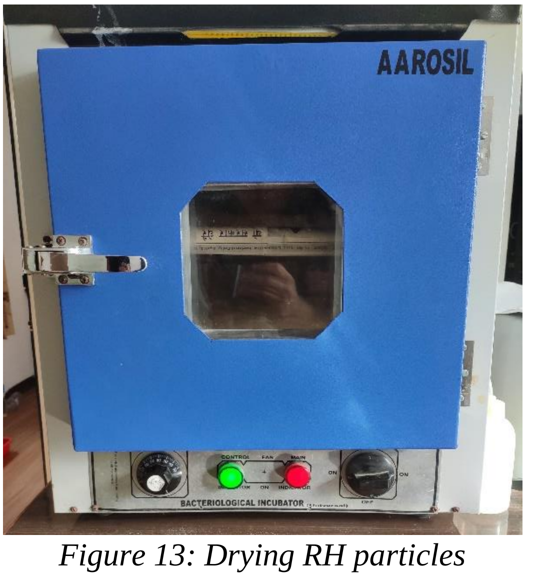

Figure 13: Drying RH particles

3.4 Sampling

After grinding and segregation, samples with different proportion of PP and RH particle were made. Three different size RH particles were separately mixed with PP in 4 different proportion as shown in the Table 1.

Table 1: Weight proportion of PP & RH of different particle size

% of RH (W/W)	**212 microns**		**425 microns**		**1000 microns**	
	RH (in gm)	PP (in gm)	RH (in gm)	PP (in gm)	RH (in gm)	PP (in gm)
10	30	270	60	540	60	540
20	60	240	120	480	120	480
30	90	210	180	420	180	420
40	120	180	240	360	240	360
Total	300	900	600	1800	600	1800

12 samples were made to process into extruder at 220ºC. Likewise, another 4 samples of 1000 micron RH particles at 10% and 40% proportion were made for higher temperature i.e., at 250ºC and 280ºC.

3.5 Processing

The prepared samples were fed into the extruder through hopper as shown in figure 14. A rotating screw inside the heated tube of extruder forwards the feed towards nozzle. The molten product, out of the nozzle, was let into slender die, with length of 1.5 meter and cross section of 1.5 cm x 4 cm.

Figure 14: Extruder

3.6 Post-processing

The pieces so obtained were dipped into water for cooling and extracted by pushing with mandrel of suitable thickness. The Specimen so obtained were divided into further segments of different dimensions according to the tests to be performed.

3.7 Testing

The testing includes mechanical testing, like tensile and impact, and morphological study. The sample specimens were made according to the type of test to be performed. Various result data of each sample piece were taken for comparison.

3.7.1 Tensile testing

For tensile test, the gauge length is calculated with formula

Gauge length = $5.65\sqrt{A} = 5.65\sqrt{(15\text{x}40)} = 138\text{mm}$

where A is the initial cross section area before loading and is independent with length, cross-section shape and type of material being tested (*[Solved] Gauge Length of Steel Specimen as per Codal Provision Is: W*, n.d.). The sample for the testing were cut at length greater than 200mm so that the extra length is used to clamp with the jaw of the universal testing machine (UTM).

3.7.2 Charpy-Impact testing

for the impact test, samples of dimension 50cm length, 10cm x 10cm of cross section with 2mm deep notch at center were made.

3.7.3 Water absorption testing

For the water absorption test, it involves determining the percentage increase in weight of the specimen through the ASTM D570 standard procedure. In this setup, the specimens were subjected for 1 hour drying period in an oven at 105ºC (*ASTM D570 - Micom Laboratories*, n.d.). Afterward, the samples were immediately weighted and submerged in water at room temperature for a 24 hours period, which afterward soaked and re-weighted for the computation of water absorption using the equation

$$\text{Water absorption \%} = \frac{wet\ weight - dry\ weight}{dry\ weight} \times 100\ \%$$

3.8 Final data comparison and conclusion

Finally, every data, that were taken from each sample with different rice husk proportion, particle size and molding temperature were compared and optimal parameter for making a composite of PP & RH was determined.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

4.1 Visual comparison

Before any further testing of those samples, visual inspection is done. With this inspection, some distinct characteristics were observed. First of all, the higher temperature samples were darker in color & fragile in nature. The fragility of such sample was more distinct at 280ºC, as the material got charred severely. Likewise, due to low viscosity and shrinkage, some samples were observed having hollow structure in its cross section which are shown in figure 15 and 16.

Figure 15: Charred sample due to high temperature

.

Figure 16: Hollow cross section

4.2 Testing

4.2.1 Tensile test

Each sample were cut into suitable dimension, for clamping with jaw of UTM, as following:

Gauge length = 138mm, Width = 40mm, and Thickness = 15mm

The data obtained from the tensile test are as shown in table 2.

Table 2: Tensile stress and elongation for below 212 microns samples

RH %	Ultimate Load (KN)	Ultimate Stress (MPa)	Yield Load (KN)	Yield Stress (MPa)	Elongation (mm)	Optimal sample
10	20.7	34.5	8.38	13.96667	15.9	
20	20.6	34.33333	8.39	13.98333	15.3	
30	23	38.33333	9.17	15.28333	21.7	✓
40	22	36.66667	9.3	15.5	14.5	

From table 2, it is seen that the ultimate tensile stress is maximum in sample of 212 microns RH particle filled with 30% by weight at 220ºC. It is also observed that the tensile stress and elongation gets increased first (up to 30%) and then decreased with increase in RH%. However, yield stress gets increased with filler percentage.

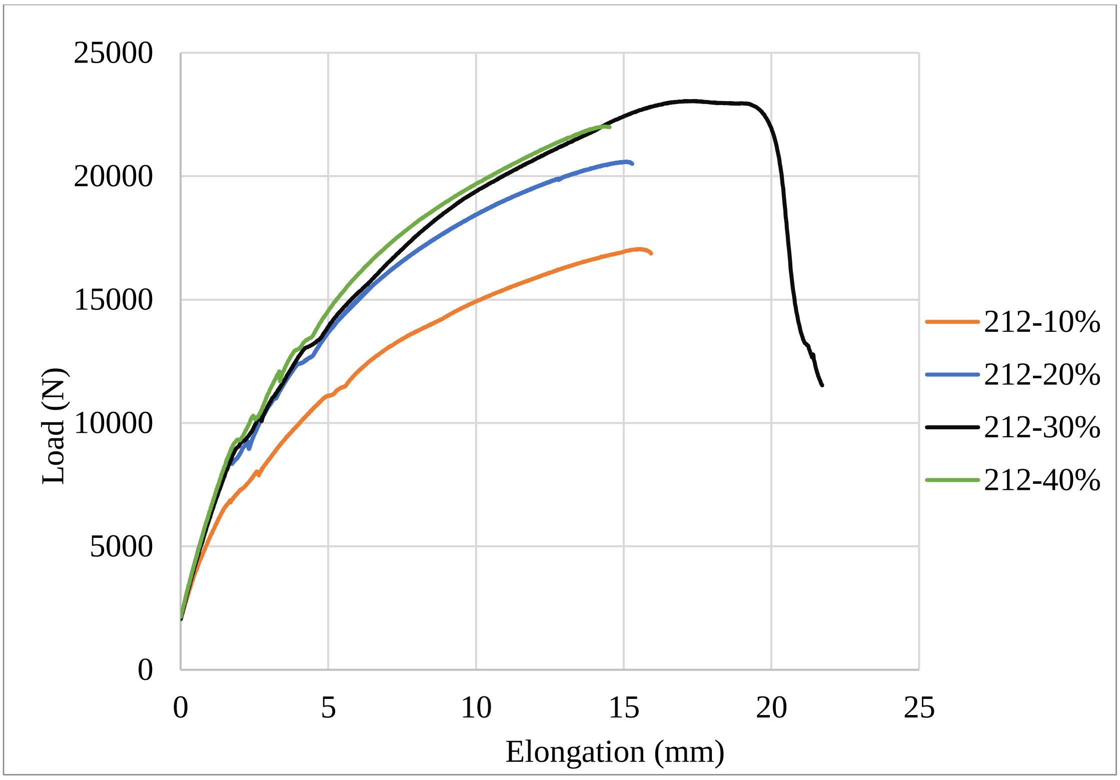

Figure 17: Below 212 micron particle size tensile stress comparison

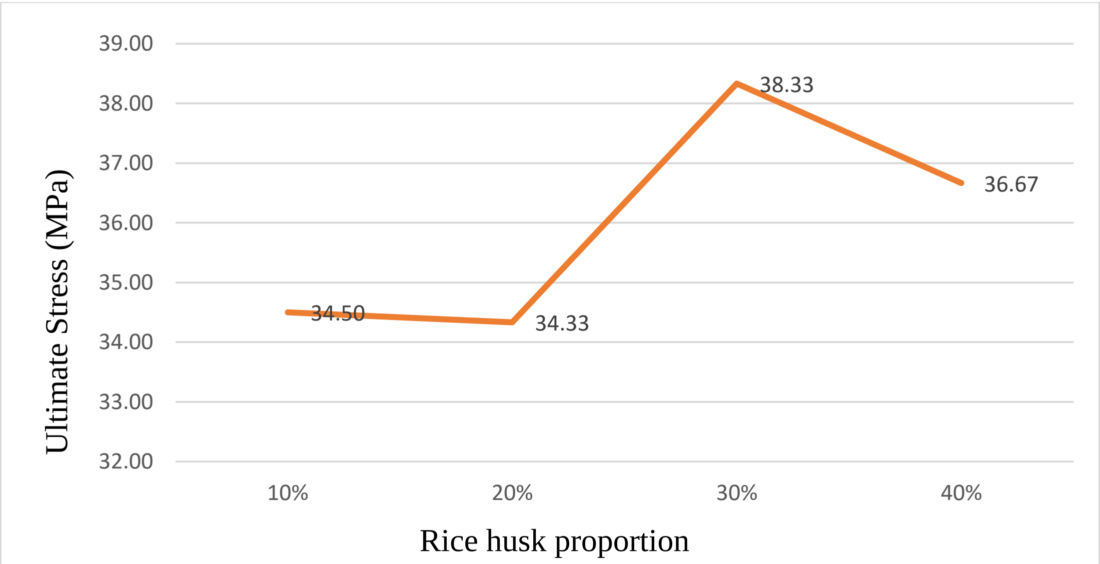

Figure 18: Ultimate stress comparison of below 212 microns sample

Figure 18 shows that the ultimate tensile strength for below 212 microns sample was found to be higher in 30% proportion sample with 38.33 MPa.

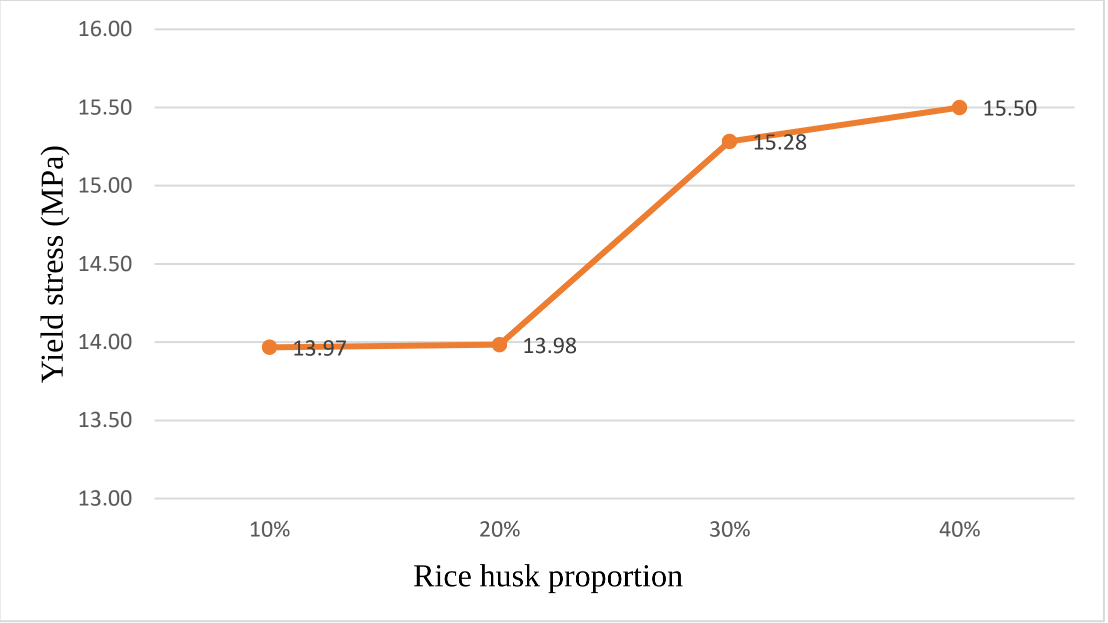

Figure 19: Yield stress comparison of below 212 microns sample

From figure 19, it can be observed that, the yield strength was maximum at 40% proportion sample with 15.5 MPa and it went decreasing with decrease in RH proportion.

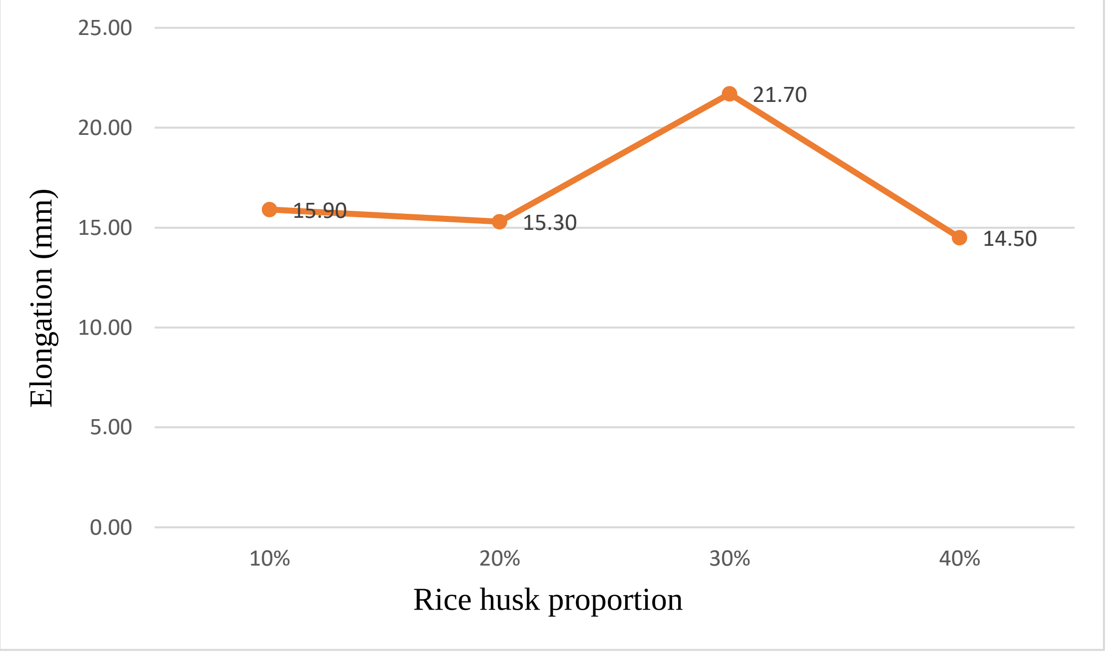

Figure 20: Elongation comparison of below 212 microns sample

Figure 20 depicts that the sample with 30% proportion gave higher elongation of 21.7mm. Similarly, the test results for sample of rice husk particle size of 212 to 425 microns are as shown in the table 3.

Table 3: 212 to 425 microns RH particle at 220ºC

RH %	**Ultimate Load (KN)**	**Ultimate Stress (MPa)**	**Yield Load (KN)**	**Yield Stress (MPa)**	**Elongation (mm)**	**Optimal sample**
10	20.9	34.83333	8.58	14.3	16.52	
20	24	40	11.57	19.28333	17.9	✓
30	21.5	35.83333	9.81	16.35	11.69	
40	16.2	27	11.1	18.5	11.34	

From table 3, similar result was obtained when compared with below 212 microns sample. The ultimate tensile stress and elongation increased up to certain filler percentage (20% in this case) and then decreased.

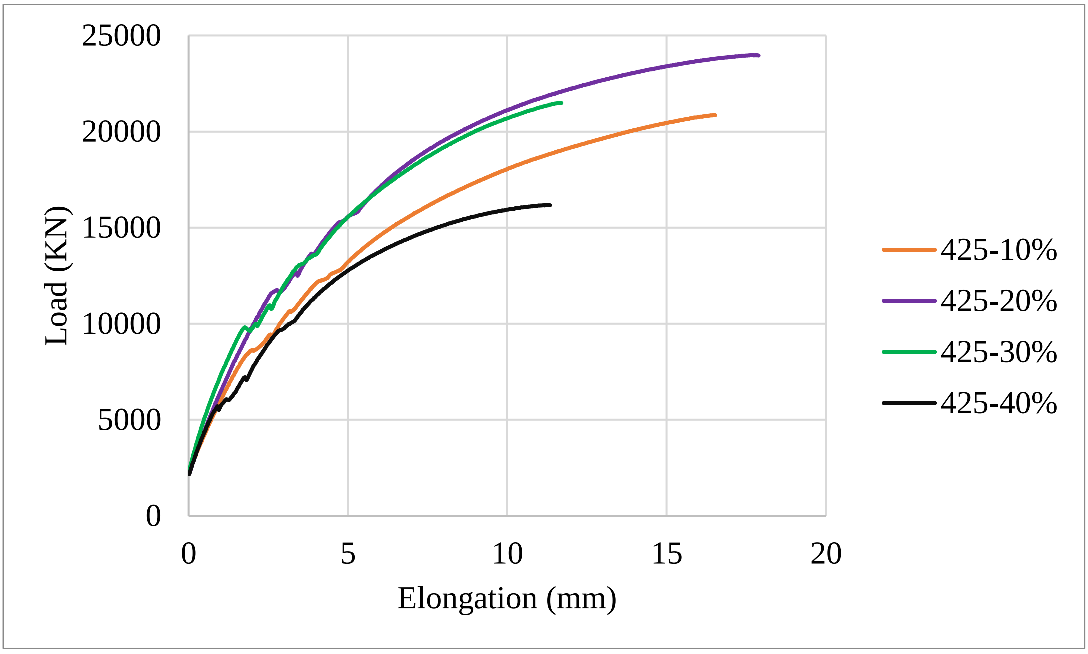

Figure 21: 212 to 425 micron particle size tensile stress comparison

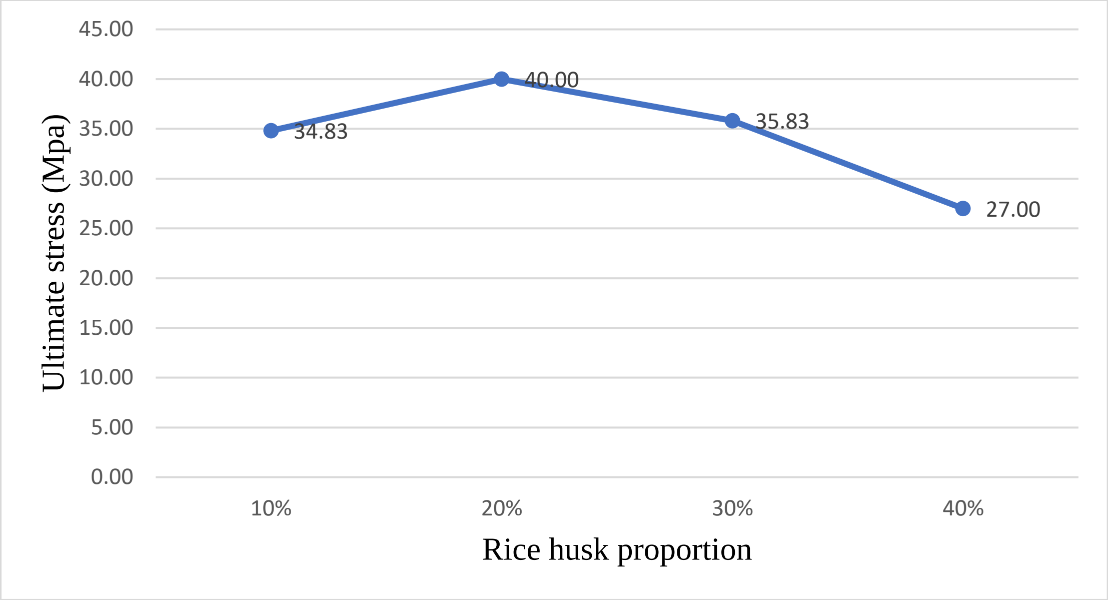

Figure 22: Ultimate stress comparison of below 212 to 425 microns sample

Figure 22 shows that the ultimate tensile strength for 212 to 425 microns sample was found to be higher in 20% proportion sample with 40 MPa.

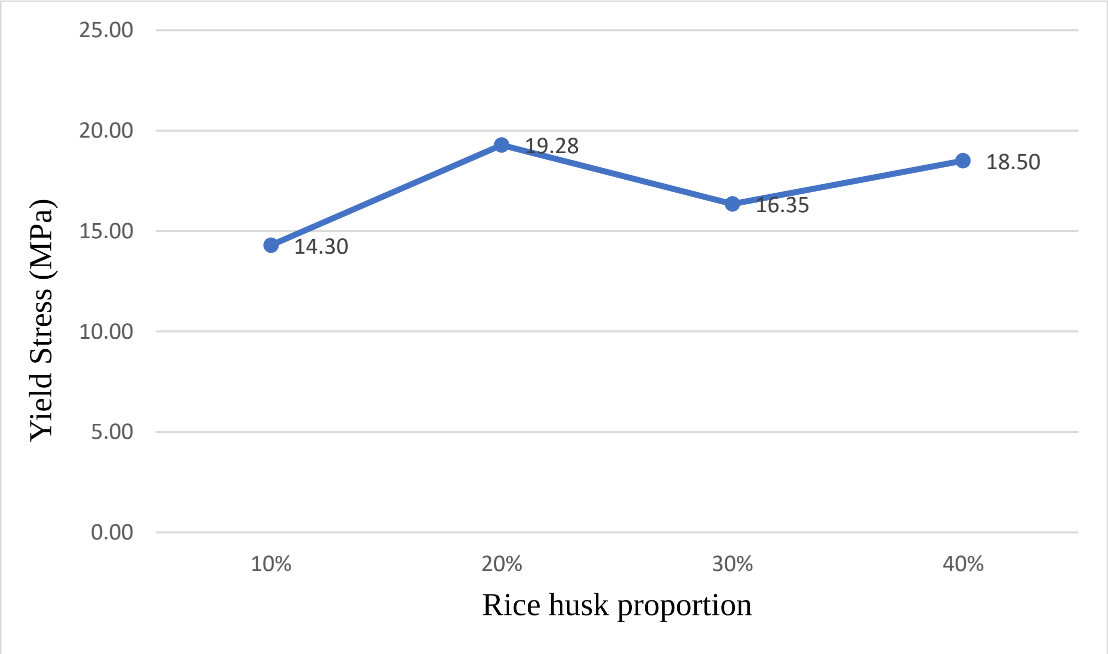

Figure 23: Yield stress comparison of below 212 to 425 microns sample

From figure 23, it can be observed that, the yield strength is maximum at 20% proportion sample with 19.28 MPa.

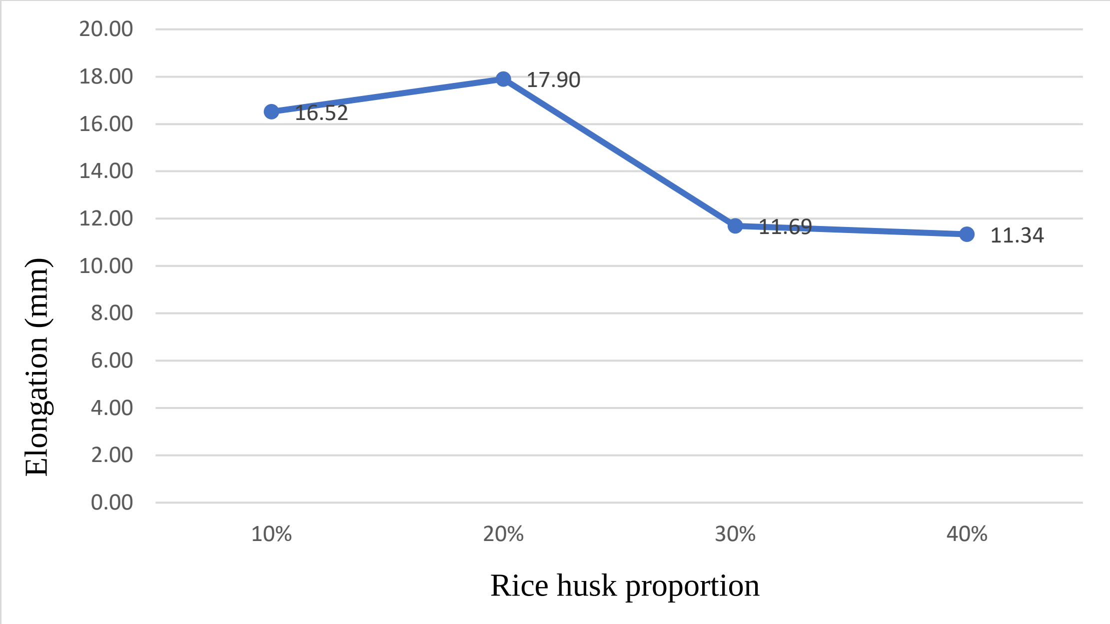

Figure 24: Elongation comparison of below 212 to 425 microns sample

Figure 24 depicts that the sample with 20% proportion gave higher elongation of 17.9mm Similarly, the test results for sample of rice husk particle size of 425 to 1000 microns are as shown in the table 4.

Table 4: 425 to 1000 microns RH particle at 220ºC

RH %	**Ultimate Load (KN)**	**Ultimate Stress (MPa)**	**Yield Load (KN)**	**Yield Stress (MPa)**	**Elongation (mm)**	**Optimal sample**
10	21.1	35.167	8.14	13.567	15.45	
20	21.3	35.5	12.6	21	9.68	✓
30	18.1	30.167	9.78	16.3	8.11	
40	14.2	23.67	8.05	13.417	6.84	

Analyzing the table 4, it is observed that there is increase in ultimate tensile stress and yield stress up to certain proportion (20%) and gets decreased onwards. However, elongation got decreased with increase in proportion.

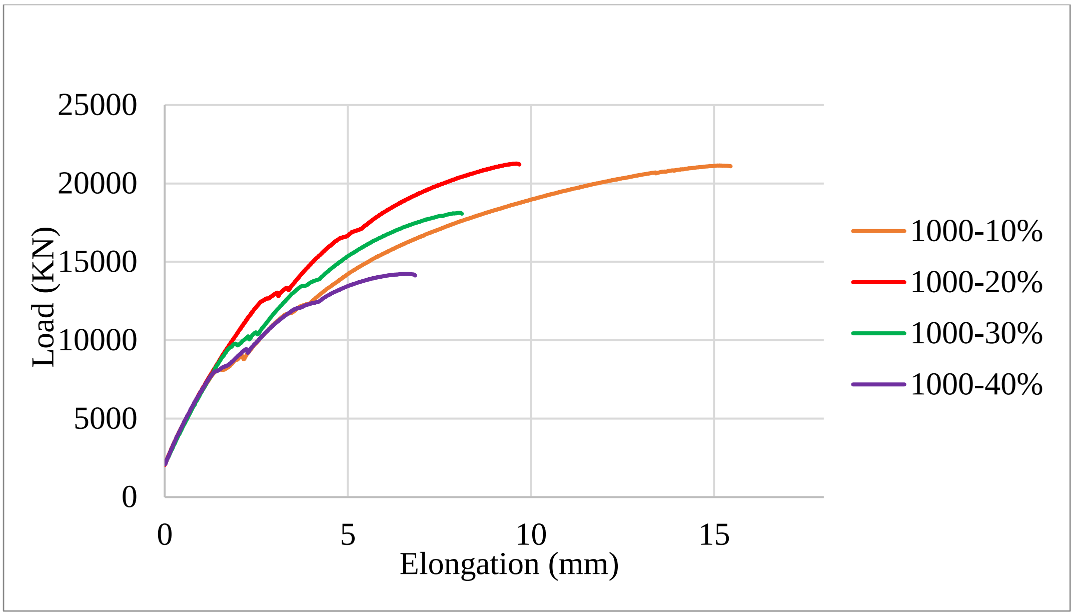

Figure 25: 425 to 1000 microns particle size comparison (Load Vs Elongation)

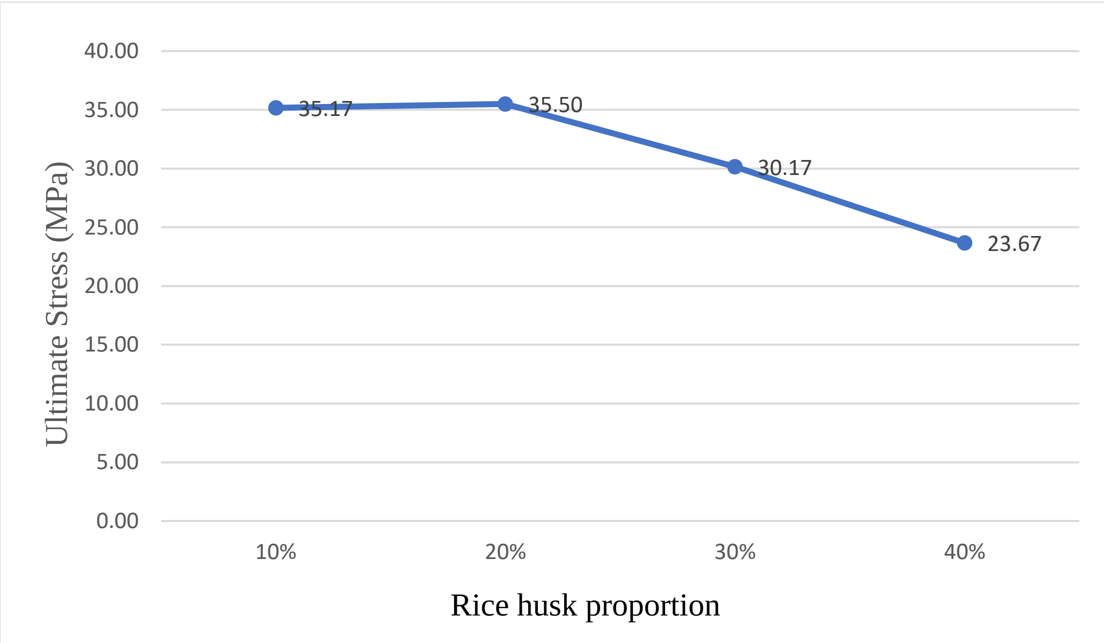

Figure 26: Ultimate stress comparison of 425 to 1000 microns sample

Figure 26 shows that the ultimate tensile strength for 425 to 1000 microns sample is found to be higher in 20% proportion sample with 35.5 MPa.

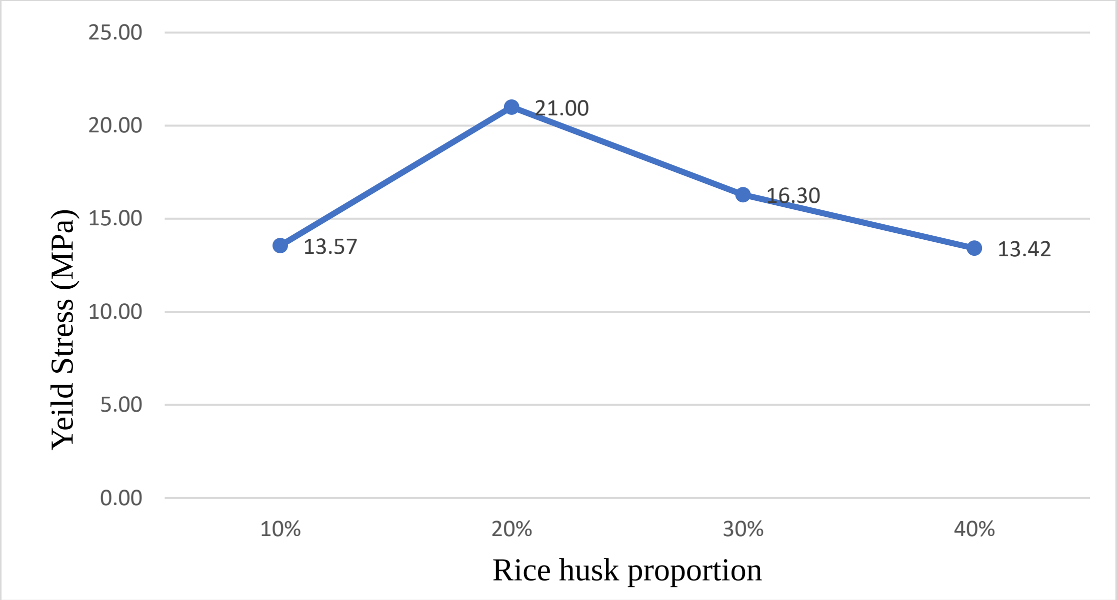

Figure 27: Yield stress comparison of 425 to 1000 microns sample

From figure 27, it can be observed that, the yield strength was maximum at 20% proportion sample with 21 MPa and it went decreasing with increase in RH proportion.

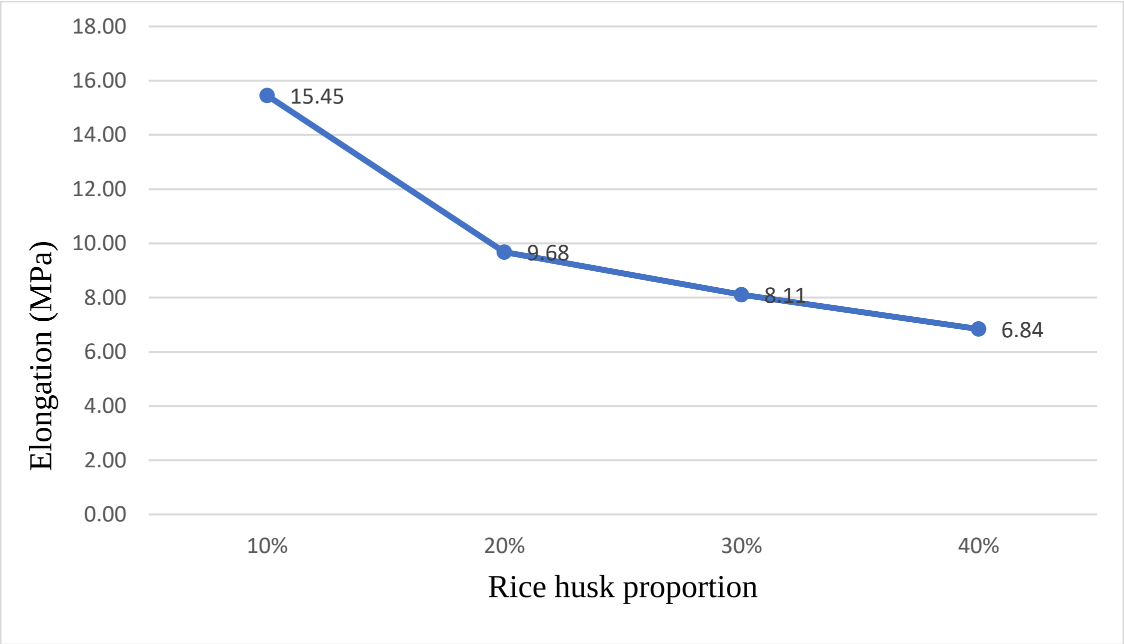

Figure 28: Elongation comparison of 425 to 1000 microns sample

Figure 28 depicts that the sample with 10% proportion gave higher elongation of 15.45mm. The increment on tensile strength with initial increase in filler proportion is due to well dispersion of particles and strong polypropylene/rice husk interface adhesion for effective stress transfer. However, the decrease in tensile strength on further increment in filler proportion is due to more filler material distribution in the matrix, leading to poor aspect ratio among matrix and filler materials. The aspect ratio indicates the amount of filler that can fill a polymer matrix Likewise, the value of ultimate tensile stress, yield stress and elongation for final data comparison is shown as in table 5.

Table 5: Final comparison with pure as well as high temperature specimen

RH particle size (micron) with RH%	**Temperature (ºC)**	**Ultimate Load (KN)**	**Ultimate stress (MPa)**	**Yield Load (KN)**	**Yield stress (MPa)**	**Elongation (mm)**	**Optimal sample**
Below 212 (30%)	220	23	38.3	9.17	15.3	21.7	
212 to 425 (20%)	220	24	40.0	11.57	19.3	17.9	✓
425 to 1000 (20%)	220	21.3	35.5	12.6	21.0	9.68	
Pure sample	220	21.1	35.2	11.7	19.5	27.6	
212 to 425 (10%)	250	19.9	33.2	9.1	15.2	14.2	
212 to 425 (40%)	250	18.8	31.3	6.3	10.5	9.3	
212 to 425 (10%)	280	17.7	29.5	5.3	8.8	9.1	
212 to 425 (40%)	280	10.1	16.8	4.4	7.3	5.6	

Table 5 shows the final comparison between optimal of the previous samples with pure and the higher temperature variant of same sample. With comparison, it has been found that sample of 212-to-425-micron 20% rice husk particle has maximum ultimate tensile stress (40 MPa) with decent yield stress (19.3 MPa), whereas the sample of 425-to-1000-micron 30% RH particle has maximum yield stress (21 MPa).

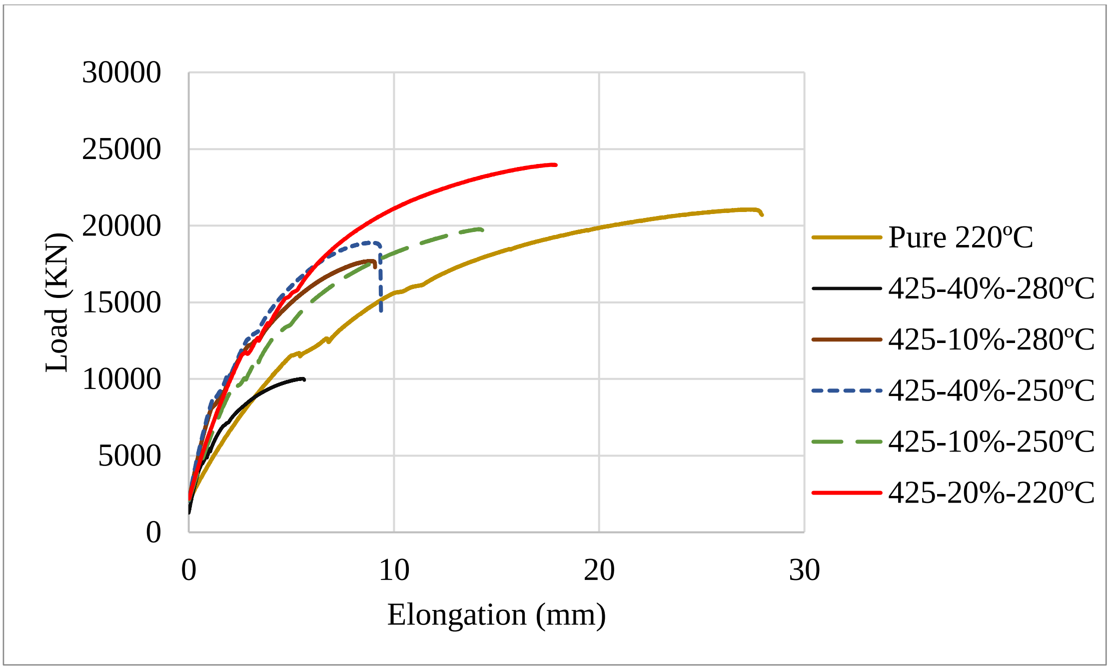

Figure 29: Overall comparison among optimal samples

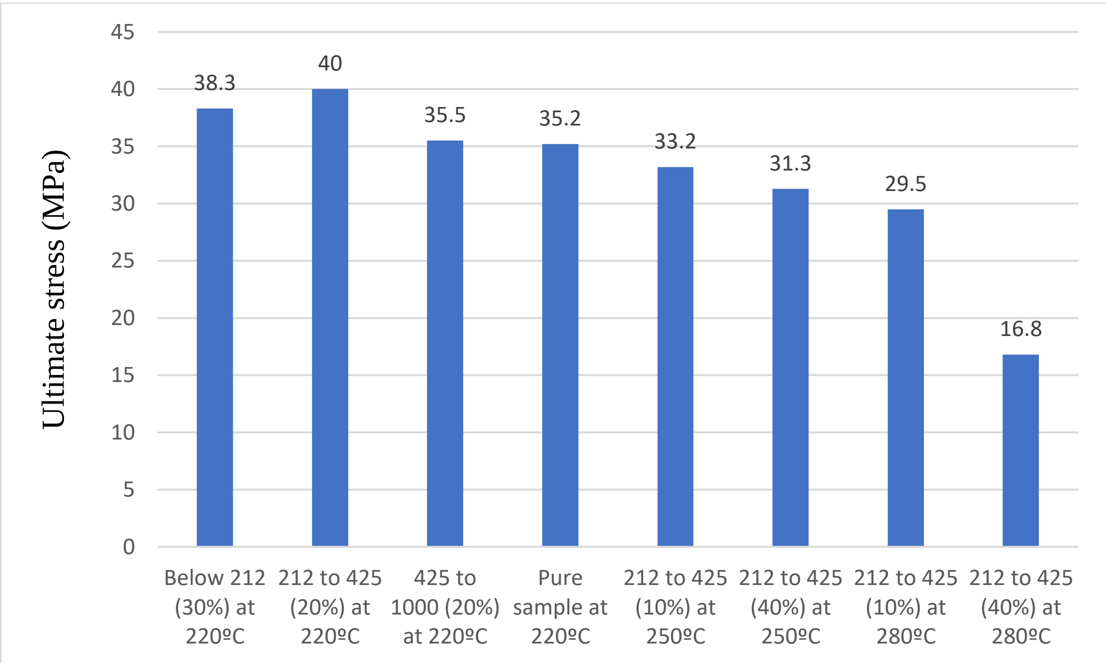

Figure 30: Ultimate stress comparison among optimal samples

From figure 30, it can clearly be seen that the 212 to 425 proportion at 20% proportion sample at 220ºC has highest ultimate tensile strength among any other sample having 40 MPa stress value.

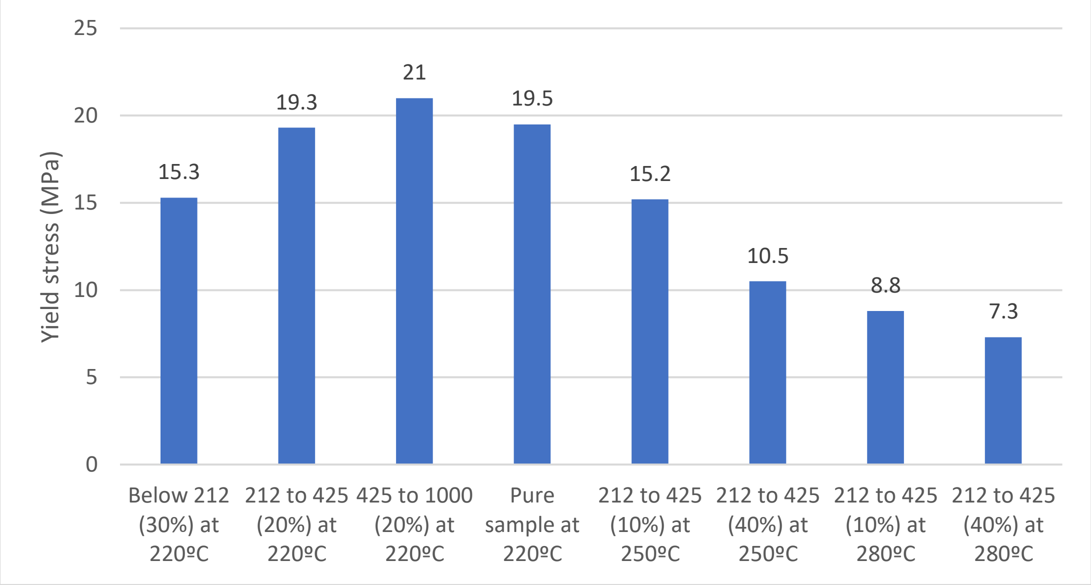

Figure 31: Yield stress comparison among optimal samples

Figure 31 depicts that the 425 to 1000 microns sample with 20% proportion at 220ºC has highest yield strength among any other sample.

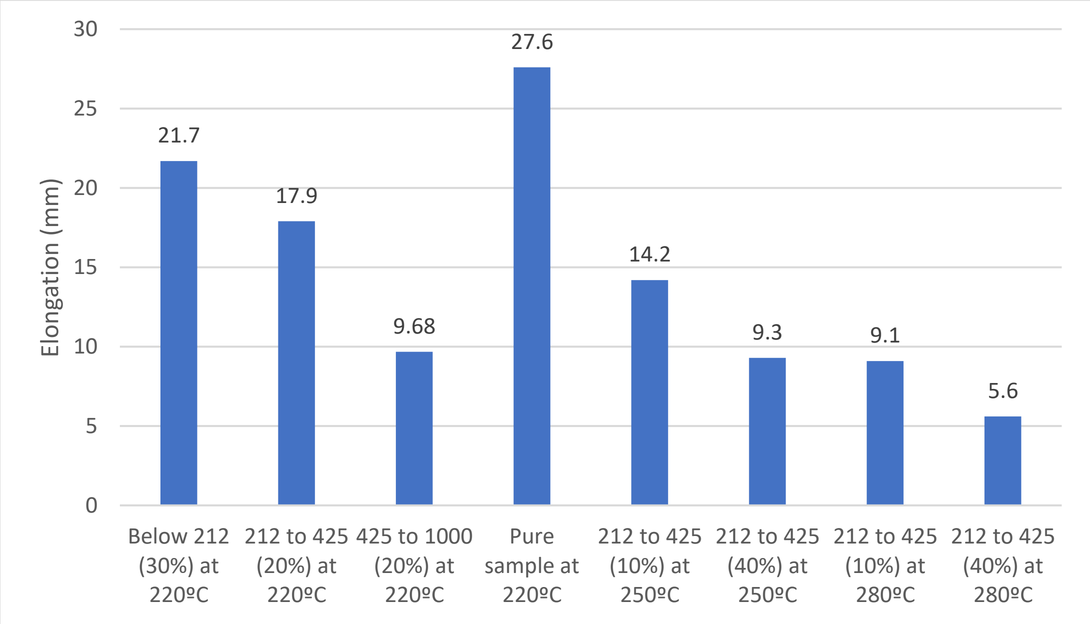

Figure 32: Elongation among optimal samples

Figure 32 shows that the elongation, however, is maximum for the pure sample with 27.6mm extended length. Among composites, sample of below 212 microns with 20% proportion at 220ºC showed higher elongation.

4.2.2 Impact test

To conduct charpy impact test, the test specimens were cut into pieces of 50mm length and 10cm x 10cm cross section and 2mm deep notch was created at central part across length as shown in figure 33.

Figure 33: Charpy impact test sample

Table 6: Impact data

Specimen	RH %	Energy division	Impact resistance (joule)	Optimal sample
Below 212 microns particle	10	0.25	0.5	
	20	0	0	
	30	0.25	0.5	
	40	0.5	1	✓
212 to 425 microns particle	10	0.75	1.5	✓
	20	0.25	0.5	
	30	0.5	1	
	40	0	0	
425 to 1000 microns particle	10	1	2	✓
	20	0.5	1	
	30	1	2	✓
	40	0.75	1.5	
Pure polypropylene	0	0.75	1.5	

Table shows the result obtained from charpy impact test. Most of the composites had impact resistance lower than that of pure polypropylene sample. Although at 20% of below 212 sample and 40% of 212 to 425 sample had shown 0 reading in energy division, it means that the impact resistance is below 0.5 joule which the tip of reading did not reach the minimum resolution of division scale. Only the sample of 425 to 1000 microns particle at 10 and 30% proportion seemed to be outperforming the toughness of pure polypropylene sample.

4.2.3 Water absorption test

Table 7 shows the water absorption test reading obtained before and after dipping the sample of suitable mass (20 to 30 grams) into water for 24 hours. The result shows that the pure polypropylene sample absorbed the least water giving just 2.96% increment in weight. In each RH size specimen, 40% proportion sample gained the most weight and 10% sample the least. Likewise, for same proportion in general, below 212 microns sample absorbed the most and 425 to 1000 microns sample the least. The water absorption of 212 to 425 sample was in between smaller and larger particle sized sample.

Table 7: Water absorption data

RH size	RH %	Dry weight (in gram)	Wet weight (in gram)	Δ weight	% Δ weight
Below 212 microns	10	24.736	26.405	1.669	6.75
	20	24.951	26.744	1.793	7.19
	30	20.632	22.637	2.005	9.72
	40	26.902	29.788	2.886	10.73
212 to 425 microns	10	21.421	22.898	1.477	6.90
	20	22.844	24.364	1.520	6.65
	30	25.058	27.200	2.142	8.55
	40	28.965	31.601	2.636	9.10
425 to 1000 microns	10	28.471	30.369	1.898	6.67
	20	24.988	26.607	1.619	6.48
	30	27.4	29.576	2.176	7.94
	40	26.132	28.357	2.225	8.51
Pure	0	23.441	24.134	0.693	2.96

4.2.4 Morphological property

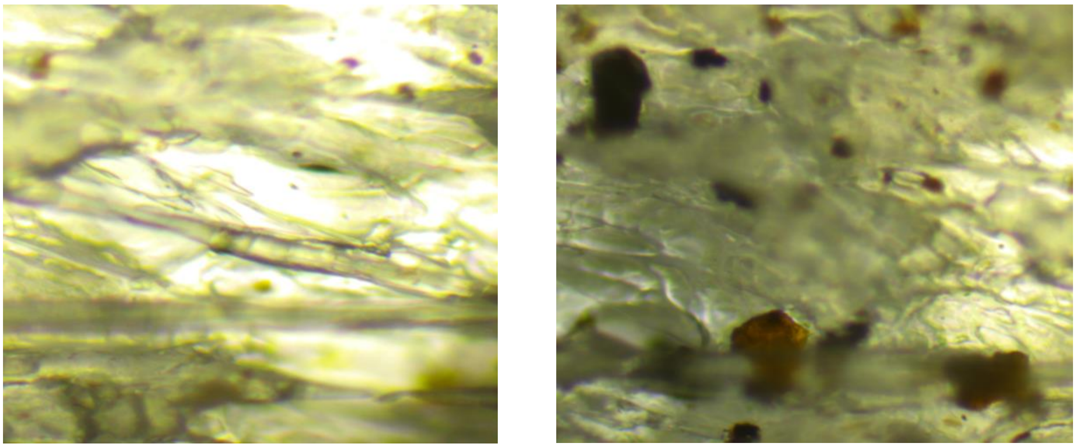

Figure 34: Structure of pure and 10% fibre filled sample

To observe the mixing and distribution of filler material on matrix, Stereo microscope, with 100 times optical and further 10 times digital magnification, was used. As in the figure 34, it can be observed that, the structure is clear in case of pure sample and there were few opaque particles in sample with 10% filler proportion of 425 to 1000 microns filled size samples. Similarly, the magnified structure image of 20%, 30% and 40% of same filler size samples are as in figure 35 and 36.

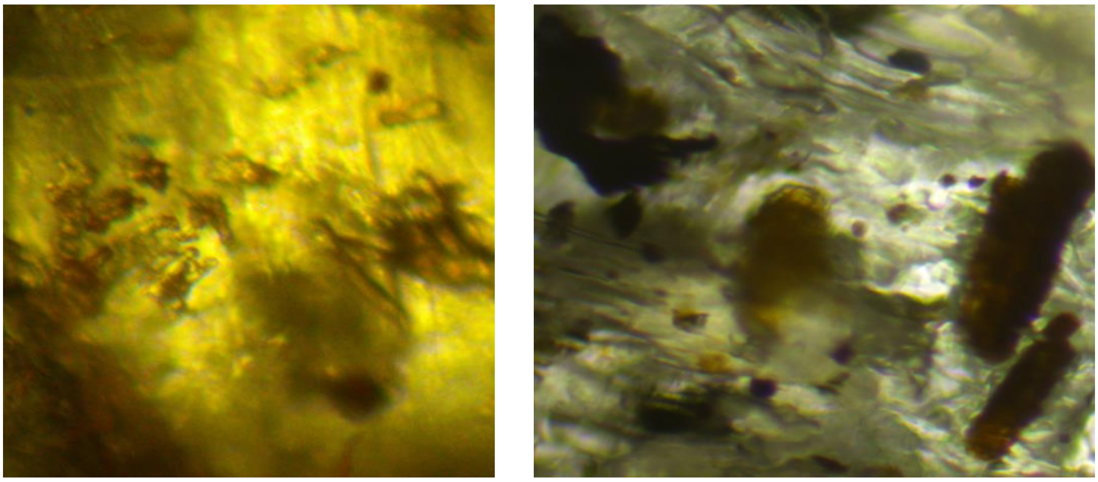

Figure 35:Structure of 20% and 30% filled sample

The distribution of filler material at lower proportion seemed to be better when compared to higher proportion samples, especially at 40% where the filler particles were clumped up in a bulk demonstrating poor dispersion. This poor distribution of filler material on the matrix for higher proportion and filler size has lead to lower mechanical strength comparetively. Similarly, the elongation was also lowered due to non-smooth bonding at higher proportion and lower cross section area of contact for bonding in case of larger filler particles. The dispersion of filler with small micro discontinuities were also observed in the composite which shows non-homogenious mixing of rice husk and polypropylene that depends on how the composite material was manufactured (Ferreira et al., 2022).

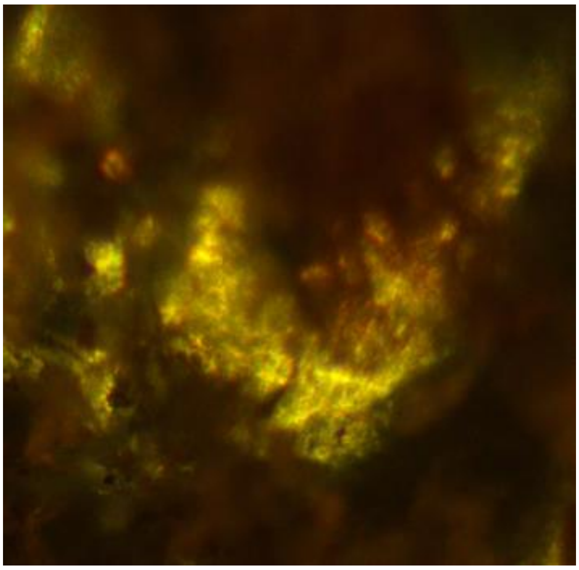

Figure 36: Structure of 40% filled sample

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The addition of rice husk into polypropylene composite has shown mostly positive insight to enhance the mechanical property. Examining the samples in various tests has given lots of findings. Regarding those findings, lots of deductions can be inferred. The visual inspection has shown the distribution of rice husk particle through the composite in both cross section as well as longitudinal pattern. Although the distribution pattern was somewhat irregular, the bonding between the matrix and filler material seemed to be strong. Similarly, the churning of the composite can be easily seen though visual inspection when the samples were extruded in higher temperature.

With tensile test, it has been observed that, in all rice husk particle size composite, the ultimate load was increased up to certain extent and got declined afterwards. Overall, samples of rice husk particle with size 212 to 425 micron seemed to be more promising in enhancement of tensile property as 20% proportion sample has touched 40 MPa tensile strength. However, in case of yield strength, higher particle size seemed to be having greater value specially at 20% exceeding 20MPa yield stress value. Similar trends were not observed in case of elongation. In general, the elongation was found to be decreasing with increasing sample size. Pure polypropylene sample has the maximum elongation followed by below 212 microns rice husk particle composite with maximum value at 30% proportion which is similar to tensile strength data. Then, the higher particle size composite has elongation in decreasing order with particle size too. When samples made with higher extruding temperature were tested, it showed drastic reduction in tensile value as well as elongation. The sample in itself was too brittle for the test having poorer outcome with increasing extruding temperature sample.

In impact test, there was not significant improvement on composite when compared with pure polypropylene sample. Although, in some proportion the result seemed to be improved, mostly it was found less tough. Overall, sample piece with greater particle size showed better impact result. So, beside samples at some specific particle size and proportion, the composites were not seemed to be practical for usage where higher toughness is the requirement, when compared with pure polypropylene sample.

To determine hygroscopic property of the composite, each sample pieces were dipped into water and dried according to ASTM D570. The data of weight variation were plotted, observed and found that the pure polypropylene sample absorbed least amount of water depicting lesser weight gain. The data also showed that the higher the amount of rice husk proportion in the composite, the more amount of water it absorbed. However, the composites with larger rice husk particle absorbed lesser moisture compared to smaller particle sample. Beside pure polymer sample, specimen of 425 to 1000 microns particle size with 20% filler proportion contained the least amount of moisture.

The morphological study showed good distribution of filler particle in the matrix, although that held true only for smaller filler particles and at lower proportion. The larger particles seemed to be clumped up together and made the sample non-uniform. The dispersion of filler material, on every composite, was non-homogeneous throughout the matrix.

5.2 Recommendations

i. The finishing of composite material could have been smoother if further smaller RH particles were taken.

ii. The extrusion process could produce better dispersion and uniform distribution of filler material using other techniques like melt mixing.

iii. Although the optimal sample was obtained at 20% filled 425 to 1000 microns filler size, the result could further be improved by choosing the samples with closer filler size and proportion of the optimal condition of this study.

iv. The morphological analysis could be taken further in depth if X-ray Diffraction (XRD) and Scanning Electron Microscope (SEM) was to be used

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ANNEX A: SAMPLE FORMATION

Figure A-1: Grinding filler particles

Figure A-2: Residue of rice husk particles, above 1000 microns

Figure A-3: Test samples

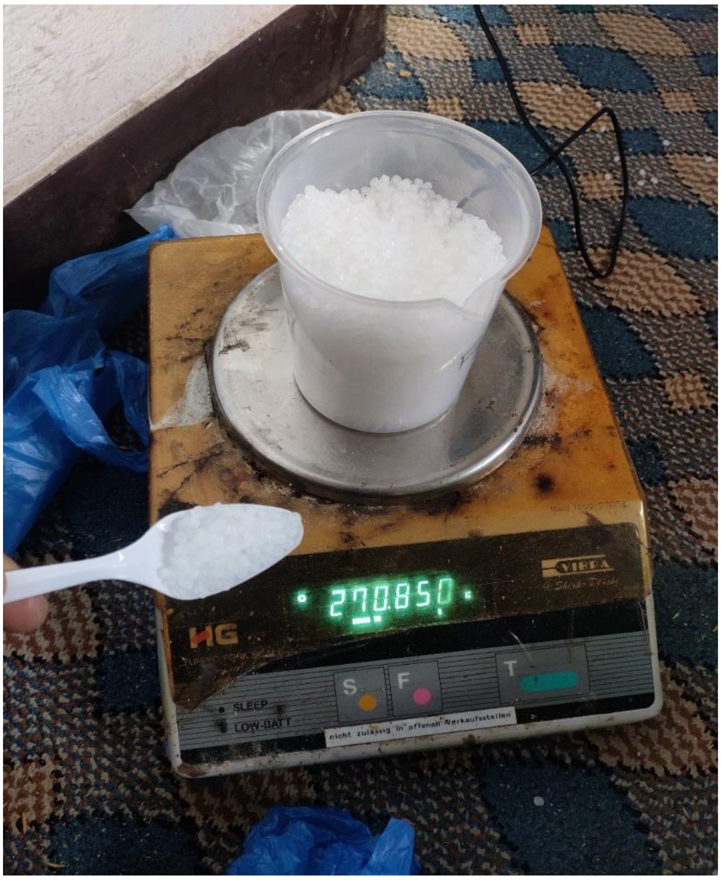

Figure A-4: weighing machine for matching exact proportion

Figure A-5: Samples for water absorption testing

Figure A-6: Drying samples at 105ºC for 1 hour

Figure A-7: RH Residue, 1000 microns, 412 micron and 212 microns (from left)

Figure A-8: Arrangement of various samples

Figure A-9: Mixing PP and RH particle

Figure A-10: Cutting of test specimen

ANNEX B: TESTING

Figure B-1: Universal Testing Machine (UTM)

Figure B-2: Test specimens after breaking in UTM

Figure B-3: Cross-section of test specimen

Figure B-4: Clamping specimen with jaws (UTM)

ANNEX C: TENSILE DATA OF THE OPTIMAL SAMPLE

(425 to 1000 microns filler size at 20% proportion at 220ºC molding temperature) obtained from Universal Testing Machine (UTM)

Jaw position	Load (newtons)	Jaw position	Load (newtons)	Jaw position	Load (newtons)
0.0209424	2192.836	6.198953	17417.14	12.09424	22271.51
0.0418848	2284.901	6.219895	17442.25	12.10471	22271.51
0.0628272	2385.336	6.240838	17475.73	12.13613	22288.25
0.0837696	2510.88	6.26178	17500.84	12.1466	22296.62
0.104712	2602.946	6.282722	17542.69	12.16754	22296.62
0.1256544	2736.86	6.303665	17559.42	12.18848	22313.36
0.1465969	2812.186	6.324607	17601.27	12.20942	22330.1
0.1675393	2929.361	6.335079	17618.01	12.23037	22338.47
0.1884817	3021.426	6.356021	17643.12	12.25131	22338.47
0.2094241	3113.492	6.376963	17676.6	12.26178	22346.84
0.2303665	3247.406	6.397906	17701.71	12.28272	22355.21
0.2513089	3331.101	6.418848	17726.82	12.30367	22380.31
0.2722513	3414.797	6.439791	17751.93	12.32461	22371.95
0.2931937	3515.233	6.450262	17777.03	12.34555	22388.68
0.3141361	3615.668	6.481676	17810.51	12.36649	22405.42
0.3350785	3716.103	6.492146	17827.25	12.37696	22405.42
0.356021	3808.169	6.52356	17869.1	12.39791	22422.16
0.3769633	3883.495	6.534031	17885.84	12.42932	22422.16
0.3979058	3992.3	6.554974	17910.95	12.43979	22430.53
0.4188482	4084.365	6.575916	17936.06	12.46073	22438.9
0.4502618	4193.17	6.596859	17961.17	12.48168	22447.27
0.460733	4260.127	6.617801	17986.27	12.50262	22455.64
0.4816754	4360.563	6.628272	18003.01	12.52356	22455.64
0.5026178	4444.258	6.649215	18036.49	12.53403	22464.01
0.5235602	4527.955	6.670157	18061.6	12.55497	22489.12
0.5445026	4636.759	6.6911	18086.71	12.57592	22489.12
0.565445	4703.716	6.712042	18111.82	12.59686	22497.49
0.5863875	4795.782	6.732984	18136.93	12.6178	22514.23
0.6073298	4896.217	6.753927	18162.04	12.62827	22505.86
0.6282722	4971.543	6.774869	18187.14	12.64921	22522.6
0.6492147	5071.979	6.795812	18203.88	12.67016	22539.34
0.6701571	5155.675	6.816754	18245.73	12.6911	22547.71
0.6910995	5239.371	6.827225	18254.1	12.71204	22547.71
0.7120419	5331.436	6.848167	18279.21	12.73298	22547.71
0.7329843	5398.393	6.86911	18312.69	12.74346	22572.82

0.7643979	5498.828	6.890052	18329.43	12.7644	22581.19
0.7748691	5574.155	6.910995	18362.91	12.78534	22589.55
0.7958115	5666.22	6.931937	18371.28	12.80628	22597.92
0.8167539	5741.547	6.952879	18404.75	12.81675	22597.92
0.8376963	5850.352	6.973822	18421.49	12.8377	22606.29
0.8691099	5942.417	6.984293	18446.6	12.85864	22623.03
0.8795812	5992.635	7.005236	18488.45	12.87958	22623.03
0.9005235	6084.7	7.026178	18505.19	12.90052	22623.03
0.921466	6151.657	7.047121	18513.56	12.92147	22639.77
0.9424084	6235.353	7.068063	18547.04	12.93194	22648.14
1.005236	6452.963	7.078534	18555.41	12.95288	22656.51
1.005236	6452.963	7.109948	18597.25	12.97382	22664.88
1.005236	6478.072	7.120419	18605.63	12.99476	22681.62
1.036649	6570.137	7.141361	18639.1	13.01571	22681.62
1.057592	6645.464	7.162303	18655.84	13.03665	22689.99
1.078534	6745.899	7.183246	18680.95	13.05759	22698.36
1.099476	6804.486	7.204188	18706.06	13.06806	22698.36
1.120419	6879.813	7.21466	18714.43	13.09948	22715.1
1.141361	6955.139	7.235602	18739.54	13.10995	22731.84
1.162304	7038.835	7.256545	18764.65	13.13089	22723.47
1.183246	7122.531	7.277487	18789.76	13.15183	22731.84
1.204188	7189.488	7.298429	18806.49	13.1623	22731.84
1.225131	7264.814	7.319372	18831.6	13.19372	22748.58
1.246073	7340.141	7.329843	18839.97	13.20419	22756.95
1.267016	7423.836	7.361257	18865.08	13.22513	22773.69
1.287958	7507.533	7.371728	18898.56	13.24607	22773.69
1.3089	7566.12	7.403141	18915.3	13.26702	22782.05
1.319372	7633.077	7.413612	18940.41	13.28796	22790.43
1.350785	7725.142	7.434555	18948.78	13.3089	22798.79
1.361257	7792.099	7.455497	18982.26	13.31937	22807.16
1.39267	7875.795	7.47644	18999	13.34031	22815.53
1.403141	7934.382	7.497382	19024.1	13.36126	22815.53
1.424084	8018.078	7.507854	19040.84	13.3822	22823.9
1.455497	8076.666	7.528796	19057.58	13.39267	22823.9
1.47644	8160.361	7.549738	19074.32	13.42408	22840.64
1.497382	8235.688	7.570681	19107.8	13.43456	22849.01
1.518325	8294.275	7.591623	19132.91	13.4555	22857.38
1.528796	8361.232	7.612566	19141.28	13.47644	22857.38
1.560209	8436.559	7.633508	19149.65	13.48691	22874.12
1.581152	8503.516	7.65445	19174.76	13.50785	22882.49
1.602094	8587.211	7.675393	19199.87	13.5288	22882.49
1.623037	8645.799	7.696335	19224.97	13.54974	22899.23

1.643979	8712.755	7.706806	19233.34	13.57068	22899.23
1.664922	8779.712	7.727749	19258.45	13.59162	22907.6
1.685864	8855.038	7.748691	19275.19	13.60209	22924.34
1.706806	8930.365	7.769633	19308.67	13.62304	22924.34
1.727749	8997.321	7.790576	19325.41	13.64398	22941.08
1.748691	9039.17	7.811518	19350.52	13.66492	22949.45
1.759162	9131.235	7.82199	19358.89	13.68586	22949.45
1.790576	9189.822	7.842932	19375.63	13.70681	22957.82
1.811518	9248.41	7.863874	19392.37	13.72775	22966.19
1.832461	9315.366	7.884817	19425.85	13.73822	22966.19
1.842932	9373.954	7.905759	19434.21	13.76963	22974.56
1.863874	9449.28	7.91623	19450.96	13.7801	22982.93
1.884817	9507.867	7.937173	19467.69	13.80105	22999.67
1.91623	9583.193	7.958115	19484.43	13.82199	22999.67
1.926702	9633.411	7.989529	19509.54	13.84293	23008.04
1.947644	9733.847	8	19517.91	13.86387	23016.4
1.968586	9775.694	8.020943	19551.39	13.87435	23016.4
1.989529	9825.912	8.031414	19559.76	13.89529	23033.14
2.010471	9892.869	8.052356	19576.5	13.91623	23024.77
2.031414	9976.565	8.073298	19601.61	13.93717	23041.51
2.052356	10018.41	8.094241	19618.35	13.95812	23049.88
2.073298	10085.37	8.115183	19618.35	13.96859	23049.88
2.094241	10143.96	8.136126	19660.19	13.98953	23058.25
2.115183	10227.65	8.157068	19651.82	14.01047	23066.62
2.136126	10294.61	8.178011	19693.67	14.03141	23074.99
2.146597	10344.83	8.188481	19702.04	14.05236	23083.36
2.17801	10378.31	8.209424	19727.15	14.06283	23091.73
2.198953	10445.26	8.230367	19743.89	14.08377	23091.73
2.219895	10537.33	8.251308	19760.63	14.10471	23100.1
2.230366	10587.55	8.272251	19777.37	14.12565	23116.84
2.251309	10629.39	8.293194	19794.11	14.1466	23108.47
2.272251	10687.98	8.314137	19810.85	14.16754	23125.21
2.293194	10746.57	8.324607	19819.22	14.17801	23125.21
2.324607	10830.26	8.356021	19835.96	14.19895	23133.58
2.335078	10888.85	8.366492	19861.06	14.2199	23150.32
2.356021	10930.7	8.387435	19869.43	14.24084	23150.32
2.376963	11014.4	8.408377	19886.17	14.26178	23167.06
2.397906	11047.87	8.429319	19919.65	14.28272	23158.69
2.418848	11114.83	8.450262	19919.65	14.29319	23167.06
2.43979	11165.05	8.471204	19944.76	14.31414	23175.43
2.460733	11223.64	8.481675	19961.5	14.33508	23183.8
2.481675	11282.22	8.502618	19969.87	14.35602	23192.17

2.502618	11340.81	8.523561	19986.61	14.36649	23192.17
2.52356	11416.14	8.544502	20011.72	14.38743	23200.54
2.544503	11457.98	8.565445	20028.46	14.40838	23200.54
2.565445	11508.2	8.575916	20028.46	14.42932	23217.28
2.575916	11550.05	8.596859	20053.57	14.45026	23225.64
2.60733	11591.9	8.617801	20070.3	14.4712	23234.01
2.628272	11625.38	8.638743	20087.04	14.49215	23234.01
2.649215	11625.38	8.659686	20103.78	14.51309	23242.38
2.659686	11642.12	8.670157	20137.26	14.53403	23234.01
2.680628	11667.22	8.691099	20128.89	14.5445	23250.75
2.701571	11692.33	8.712042	20154	14.56544	23259.12
2.722513	11709.07	8.732985	20170.74	14.58639	23250.75
2.743455	11717.44	8.753926	20187.48	14.60733	23275.86
2.764398	11750.92	8.774869	20204.22	14.62827	23275.86
2.78534	11742.55	8.795812	20220.96	14.64921	23284.23
2.806283	11709.07	8.816754	20237.7	14.65969	23284.23
2.827225	11658.86	8.837696	20254.44	14.68063	23292.6
2.848168	11642.12	8.858639	20254.44	14.70157	23300.97
2.86911	11633.75	8.86911	20287.91	14.72251	23317.71
2.890052	11658.86	8.890053	20304.65	14.73298	23309.34
2.910995	11675.59	8.910995	20313.02	14.75393	23326.08
2.931937	11717.44	8.931937	20338.13	14.77487	23326.08
2.95288	11750.92	8.95288	20346.5	14.79581	23334.45
2.973822	11792.77	8.973822	20363.24	14.81675	23342.82
2.994764	11826.25	8.984293	20371.61	14.82722	23342.82
3.015707	11868.09	9.005236	20388.35	14.84817	23334.45
3.036649	11918.31	9.026178	20405.09	14.86911	23359.56
3.04712	11960.16	9.04712	20430.2	14.89005	23359.56
3.068063	11993.64	9.068063	20438.57	14.91099	23367.93
3.089005	12052.23	9.089005	20446.94	14.92147	23376.3
3.109948	12102.44	9.099477	20463.68	14.94241	23376.3
3.141361	12161.03	9.120419	20480.42	14.96335	23384.67
3.151832	12211.25	9.141361	20497.15	14.98429	23393.04
3.172775	12269.84	9.162304	20522.26	15.00524	23393.04
3.193717	12320.05	9.183246	20530.63	15.02618	23401.41
3.21466	12378.64	9.204188	20530.63	15.03665	23401.41
3.235602	12428.86	9.21466	20564.11	15.05759	23409.78
3.256545	12487.45	9.235602	20580.85	15.07853	23418.14
3.277487	12512.55	9.256544	20589.22	15.09948	23426.52
3.298429	12571.14	9.277487	20605.96	15.12042	23434.88
3.319372	12612.99	9.287958	20614.33	15.13089	23434.88
3.340314	12654.84	9.308901	20622.7	15.15183	23434.88

3.361257	12679.95	9.340314	20639.44	15.17278	23434.88
3.382199	12679.95	9.350785	20647.81	15.19372	23451.62
3.39267	12612.99	9.371728	20664.55	15.21466	23468.36
3.413613	12495.82	9.392671	20689.65	15.2356	23468.36
3.434555	12529.29	9.413612	20698.03	15.24607	23459.99
3.455497	12579.51	9.434555	20714.76	15.26702	23476.73
3.47644	12654.84	9.455498	20731.5	15.28796	23485.1
3.486911	12721.79	9.465968	20739.87	15.3089	23476.73
3.507854	12797.12	9.486911	20764.98	15.32984	23485.1
3.539267	12864.08	9.507854	20773.35	15.35079	23485.1
3.549738	12905.93	9.528796	20781.72	15.36126	23501.84
3.570681	12964.51	9.549738	20790.09	15.39267	23510.21
3.591623	13031.47	9.570681	20815.2	15.40314	23510.21
3.612566	13081.69	9.591623	20823.57	15.42408	23518.58
3.633508	13148.64	9.602095	20840.31	15.44503	23526.95
3.65445	13190.49	9.633508	20865.42	15.4555	23526.95
3.675393	13232.34	9.643979	20865.42	15.48691	23535.32
3.696335	13282.56	9.664922	20882.16	15.49738	23535.32
3.706806	13324.41	9.685863	20898.89	15.51832	23543.69
3.73822	13374.62	9.706806	20907.27	15.53927	23552.06
3.748691	13424.84	9.727749	20932.37	15.56021	23560.43
3.769634	13475.06	9.748692	20932.37	15.58115	23560.43
3.790576	13516.91	9.759162	20949.11	15.59162	23568.8
3.811518	13558.75	9.790576	20965.85	15.61257	23577.17
3.832461	13608.97	9.801047	20974.22	15.63351	23568.8
3.853403	13642.45	9.83246	20999.33	15.65445	23585.54
3.874346	13500.17	9.842932	21007.7	15.67539	23593.91
3.895288	13542.02	9.853403	21007.7	15.68586	23585.54
3.91623	13575.49	9.874346	21032.81	15.70681	23593.91
3.937173	13634.08	9.895288	21049.55	15.72775	23602.28
3.958115	13659.19	9.91623	21057.92	15.73822	23610.65
3.979058	13709.41	9.937173	21066.29	15.76963	23602.28
4	13751.26	9.958116	21091.4	15.7801	23619.02
4.010471	13793.1	9.968586	21091.4	15.80105	23619.02
4.041885	13851.69	9.989529	21108.13	15.82199	23627.38
4.052356	13893.54	10.01047	21116.5	15.84293	23627.38
4.073298	13918.65	10.03141	21141.61	15.86387	23635.76
4.094241	13977.23	10.05236	21133.24	15.87435	23635.76
4.115183	14035.82	10.0733	21158.35	15.89529	23652.49
4.136126	14086.04	10.08377	21175.09	15.91623	23660.86
4.146597	14127.89	10.11518	21175.09	15.93717	23652.49
4.167539	14161.37	10.12565	21191.83	15.95812	23660.86

4.188482	14219.95	10.1466	21200.2	15.97906	23669.23
4.209424	14261.8	10.16754	21216.94	15.98953	23669.23
4.240838	14320.39	10.18848	21225.31	16.01047	23669.23
4.251309	14345.5	10.20942	21242.05	16.03141	23685.97
4.272251	14395.71	10.2199	21258.79	16.05236	23677.6
4.293194	14437.56	10.25131	21258.79	16.06283	23694.34
4.314136	14496.15	10.26178	21275.53	16.08377	23694.34
4.335079	14529.63	10.28272	21283.9	16.10471	23694.34
4.34555	14563.11	10.30367	21309.01	16.12565	23702.71
4.376963	14604.96	10.32461	21309.01	16.1466	23711.08
4.387434	14646.8	10.33508	21325.74	16.16754	23702.71
4.408377	14697.02	10.36649	21334.12	16.18848	23719.45
4.439791	14738.87	10.37696	21350.85	16.20942	23719.45
4.450262	14789.09	10.40838	21375.96	16.21989	23727.82
4.471204	14830.93	10.41885	21375.96	16.25131	23727.82
4.492146	14864.41	10.43979	21401.07	16.26178	23727.82
4.513089	14914.63	10.46073	21392.7	16.28272	23736.19
4.544503	14956.48	10.4712	21417.81	16.30367	23744.56
4.554974	14981.59	10.50262	21426.18	16.32461	23736.19
4.575916	15023.43	10.51309	21434.55	16.34555	23752.93
4.596859	15065.28	10.53403	21434.55	16.35602	23752.93
4.617801	15107.13	10.55497	21459.66	16.37696	23761.3
4.638743	15140.61	10.57592	21468.03	16.39791	23761.3
4.649215	15157.35	10.59686	21476.4	16.40838	23778.04
4.670157	15207.57	10.60733	21493.14	16.43979	23769.67
4.6911	15241.04	10.62827	21509.88	16.45026	23769.67
4.712042	15266.15	10.64921	21518.25	16.4712	23778.04
4.732984	15282.89	10.67016	21526.62	16.49215	23778.04
4.753927	15291.26	10.6911	21543.36	16.50262	23786.41
4.774869	15291.26	10.70157	21551.72	16.53403	23794.78
4.795812	15308	10.72251	21568.46	16.5445	23794.78
4.806283	15316.37	10.74346	21568.46	16.56544	23803.15
4.837697	15324.74	10.7644	21585.2	16.58639	23803.15
4.848167	15349.85	10.78534	21601.94	16.60733	23811.52
4.86911	15358.22	10.79581	21601.94	16.62827	23819.89
4.890052	15383.33	10.81675	21627.05	16.63874	23819.89
4.900524	15400.07	10.8377	21627.05	16.65969	23819.89
4.931937	15425.18	10.85864	21643.79	16.68063	23828.26
4.942409	15458.65	10.87958	21643.79	16.70157	23836.63
4.963351	15500.5	10.90052	21660.53	16.72251	23828.26
4.973822	15525.61	10.92147	21677.27	16.74346	23836.63
5.005236	15559.09	10.93194	21685.64	16.75393	23836.63

5.026178	15592.57	10.95288	21694.01	16.77487	23836.63
5.036649	15617.68	10.98429	21702.38	16.79581	23844.99
5.057591	15642.79	10.99476	21719.12	16.81675	23844.99
5.089005	15651.16	11.01571	21719.12	16.8377	23853.37
5.099476	15667.89	11.03665	21735.86	16.85864	23853.37
5.13089	15693	11.05759	21735.86	16.86911	23853.37
5.141361	15693	11.07853	21752.59	16.89005	23861.73
5.172775	15709.74	11.08901	21760.96	16.911	23853.37
5.183246	15726.48	11.10995	21769.33	16.93194	23870.1
5.204188	15734.85	11.13089	21786.07	16.95288	23878.47
5.235602	15751.59	11.15183	21802.81	16.96335	23878.47
5.256545	15768.33	11.17278	21811.18	16.98429	23886.84
5.267016	15785.07	11.19372	21819.55	17.00524	23870.1
5.287958	15801.81	11.20419	21819.55	17.02618	23886.84
5.3089	15835.29	11.22513	21836.29	17.03665	23886.84
5.340314	15885.5	11.24607	21853.03	17.06806	23895.21
5.350785	15935.72	11.26702	21869.77	17.07853	23895.21
5.371728	15977.57	11.28796	21869.77	17.09948	23895.21
5.39267	16019.42	11.3089	21886.51	17.12042	23895.21
5.413612	16061.27	11.32984	21886.51	17.14136	23895.21
5.434555	16111.48	11.34031	21903.25	17.15183	23911.95
5.455497	16136.59	11.37173	21903.25	17.17278	23911.95
5.47644	16178.44	11.3822	21928.36	17.19372	23911.95
5.486911	16211.92	11.40314	21936.73	17.21466	23911.95
5.518324	16253.77	11.41361	21936.73	17.2356	23911.95
5.539267	16295.61	11.43456	21945.1	17.25654	23920.32
5.549738	16345.83	11.4555	21953.46	17.27749	23928.69
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5.591623	16412.79	11.49738	21961.83	17.3089	23928.69
5.612566	16446.27	11.51832	21986.94	17.32984	23928.69
5.633508	16488.12	11.5288	21995.31	17.35079	23945.43
5.643979	16513.22	11.56021	22012.05	17.37173	23945.43
5.664921	16546.7	11.57068	22020.42	17.39267	23945.43
5.685864	16580.18	11.59162	22020.42	17.40314	23945.43
5.706806	16622.03	11.61257	22045.53	17.42408	23945.43
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5.769633	16730.83	11.67539	22062.27	17.48691	23953.8
5.790576	16764.31	11.68586	22070.64	17.50785	23953.8
5.811518	16797.79	11.70681	22087.38	17.51832	23953.8
5.832461	16831.27	11.72775	22087.38	17.53927	23953.8
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5.926702	16990.29	11.82199	22137.6	17.63351	23970.54
5.947644	17023.77	11.84293	22154.34	17.65445	23970.54
5.968586	17057.25	11.86387	22171.07	17.67539	23970.54
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6.146597	17325.08	12.04188	22238.03	17.84293	23970.54
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6.188482	17392.03	12.0733	22271.51	17.88482	23953.8

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